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LIGHTWEIGHT LOW DRAG FAST WATER BUOYS.(U)

DEC 76 W E COLBURN, D D RYAN

UNCLASSIFIED CGR/DC-1/77 USCG-D-5-77 NL

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**REPORT NO.** CG-D-5-77

# LIGHTWEIGHT LOW DRAG FAST WATER BUOYS



W. E. Colburn, Jr.
and
D. D. Ryan, III

December 1976

FINAL REPORT

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**PREPARED FOR**

**U.S. DEPARTMENT OF TRANSPORTATION**
**UNITED STATES COAST GUARD**
**OFFICE OF RESEARCH AND DEVELOPMENT**
**WASHINGTON, D.C. 20590**

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16. Abstract

This report presents the development of the Coast Guard fast water buoys. Fast water buoys are principally used on the "Western Rivers" (Mississippi River and its tributaries) although coastal channels where fast tidal currents exist may also require a fast water buoy.

The development of a lightweight buoy which can be used in currents up to 8 MPH was the design goal of this study. Associated with the fast current environment is a substantial amount of debris, ranging from mill grass to fallen trees. The buoys presently in use tend to submerge in fast currents and generally can only be recognized by the surface water disturbance. After design, testing, and evaluation of several types of fast water buoys, two sizes of spherical section buoys have been developed. Over 1400 of these fast water buoys are presently being procured for operational use during 1977.

The two fast water buoys were designed for complementary purposes. The larger buoy (FNR4 and FCR4) was designed to operate between 3 MPH and 8 MPH although it may be used in currents of less than 3 MPH if the suspended mooring weight (and external ballast) is over 35 pounds. This 160-pound buoy has a spherical section foam-filled hull that is 5 feet in diameter and removable hollow NUN and CAN daymarks that provide a nominal 1-1/4 mile range. This buoy will be used in open rivers (such as the lower Mississippi) and selected coastal channels where currents commonly exceed 5 MPH. The smaller buoy was designed to operate in currents of 0 MPH to 6 MPH. This 150-pound buoy has a spherical section foam-filled hull that is 4-1/3 feet in diameter and has ballast permanently attached. The removable hollow NUN and CAN daymarks provide a nominal 1 mile range. This buoy will be principally used in the pooled rivers where currents seldom exceed 5 MPH and currents below 3 MPH are common. Both buoys contain a radar reflector that provides a radar range in excess of 3/4 miles.

This report discusses the project history, initial hull selection, the hull configuration and material section process for test and prototype buoys, the persistent problem of debris collection, and the drawings and specifications of the two fast water buoys presently being procured for operational use.


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# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.


## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |

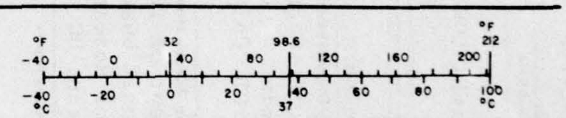


TABLE OF CONTENTS

Page

## LIST OF ILLUSTRATIONS

## 1.0 INTRODUCTION

### 1.1 Scope

This final report describes the development by the U. S. Coast Guard Research and Development Center of a four-foot and five-foot diameter spherical section Fast Water Buoy, Type FNR/FCR (Figure 1). The objective of this Fast Water Buoy project was to provide a suitable replacement for conventional 4th class and 6th class radar buoys in approximately 4500 stations in the Mississippi, Arkansas, and Missouri Rivers, as well as in other areas of the Western Rivers System where current velocities commonly exceed four miles per hour. This report documents the results of tank tests and field tests conducted between 1972 and 1976, which were supplemented by the use of a specially designed computer model. In particular, this report discusses initial hull selection, the hull configuration and material selection process for test and prototype buoys, and the persistent problem of debris collection.

### 1.2 Background

Figure 2 is a geographic illustration of a sprawling network of inland waterways called the Western Rivers System, which totals over 6000 miles in length, and which presently supports over 400 million tons of commerce each year. Figure 3 shows the typical mode of river transportation--a "raft" of between 2 to 30 barges lashed together and pushed by a single "towboat." This form of transportation boasts of being the most economical means of moving bulk goods to market. Consequently, it is a rapidly expanding industry.

Economical use of the Western Rivers System by commercial barge companies would not be possible without the channel stabilization efforts of the Army Corps of Engineers and the maintenance of an aids to navigation system by the U. S. Coast Guard. Channel stabilization began in 1874; today, approximately 70 percent of the navigable reaches of the Western Rivers have been "pooled," which means that current velocities below four miles per hour are maintained most of the year through the use of dams. The remaining 30 percent are called "open" rivers, because in these areas it is not possible to construct dams to control current flows year round. In these "open" areas (principally, the Mississippi River below St. Louis, the Missouri River, and, during certain periods of the year, the Arkansas River), current velocities exceeding four miles per hour prevail.

The maintenance of an aids to navigation system consisting of fixed shore aids (lighted and unlighted) and floating buoys (predominantly unlighted) also began in 1874. At first, primary reliance was placed upon shore aids; for example, in 1918, there were 2130 shore aids and only 500 unlighted buoys in operation. However, as the Corps' channelization efforts progressed, the Congress established the Inland Waterway Corporation (1929) to promote the use of the rivers, and the need for reliable floating aids increased significantly. Since World War II, the buoy has replaced the shore aid as the backbone of the navigational aid system. Today, of the 12,000 fixed and floating aids that comprise the system, over 9000 of them are unlighted buoys.

### 1.3 The Problem

Historically, the maintenance of a reliable floating aids to navigation system on the Western Rivers has been plagued by two problems:

FIGURE 1 - TYPE FNR/FCR SPHERICAL SECTION FAST WATER BUOY

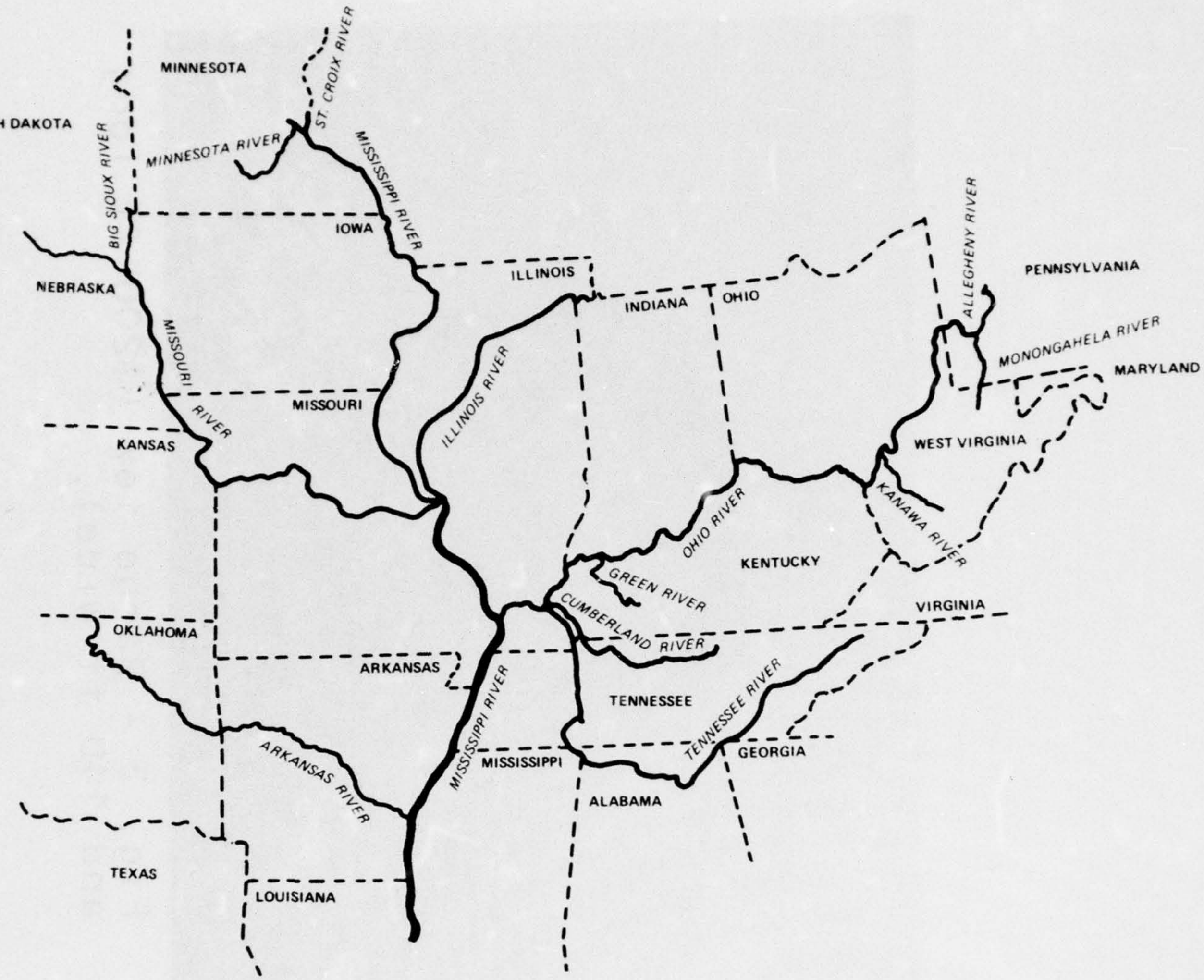



FIGURE 2 - WESTERN RIVER SYSTEM OF THE UNITED STATES

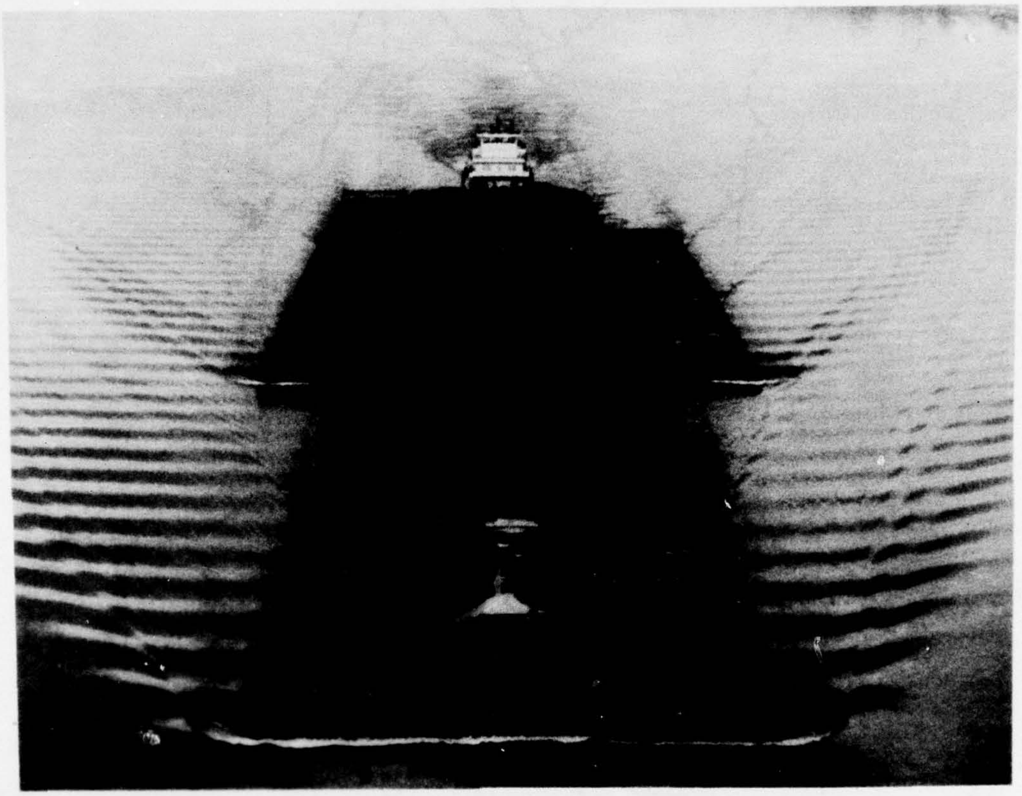


Fig. 3 - Barge tow (1200 ft long and 140 ft wide).

1. The first problem is primarily operational in nature. There have never been buoys in use on the Western Rivers that were capable of performing adequately in currents over four and five miles per hour. Today, the largest of the conventional buoys in use--the 4th class radar buoy--is pulled under the surface of the water as currents approach five miles per hour. The smaller 6th class buoy is pulled under as currents approach four miles per hour. As currents exceeding four and five miles per hour are common in the open river areas of the Western Rivers System, there was an ever-present demand for Fast Water Buoys.

2. The second problem was primarily economical in nature. Yearly losses of river buoys have consistently averaged about 57 percent of those buoys maintained on station. The loss rate in the open river areas approaches 100 percent. Coupled with the rising procurement costs for buoys and related hardware, the cost of maintaining the present aids to navigation system on the Western Rivers has increased significantly.

### 1.4 Objectives of Fast Water Buoy Project

The two problems described in Section 1.3 formed the design objectives of the Fast Water Buoy Project. Simply stated, the objective was to find a "better buoy," a Fast Water Buoy meeting these operational and economic requirements:

1. Performance Characteristics: Buoy should be capable of exhibiting required signal characteristics in currents up to eight miles per hour. It should have enough reserve buoyancy to support up to 350 pounds (dry weight) of debris; debris weight exceeding 350 pounds should cause buoy to dive and thereby shed accumulated debris, then return to normal operation. Buoy should display conventional NUN and CAN shapes and coloration.

2. Signal Characteristics: Buoy daymark should be visible for one mile under average conditions. Radar reflector should provide a target up to .75 mile, minimum range.

3. Buoy Durability: Buoy should be as impact resistant as possible, capable of sustaining collision with typical river traffic and then return to normal operation. Buoy should be unsinkable, capable of floating even if holed. Minor repairs to buoy hull should be capable of being performed by field personnel.

4. Buoy Maintenance/Storage: Buoy should require minimum hull maintenance to assure a service life of at least six years. Buoy hull shall be capable of being stored in large quantities aboard river tenders (Figure 4), either by being stacked or nested. Buoy should weigh 70 pounds maximum, and be capable of being manhandled aboard river tenders.

5. Mooring Hardware: Buoy should be equipped with a mooring eye and a lifting eye, located above the waterline. All mooring attachments should be compatible with hardware presently in use.

6. Cost: Unit cost should be $75 or less (1972 objective).

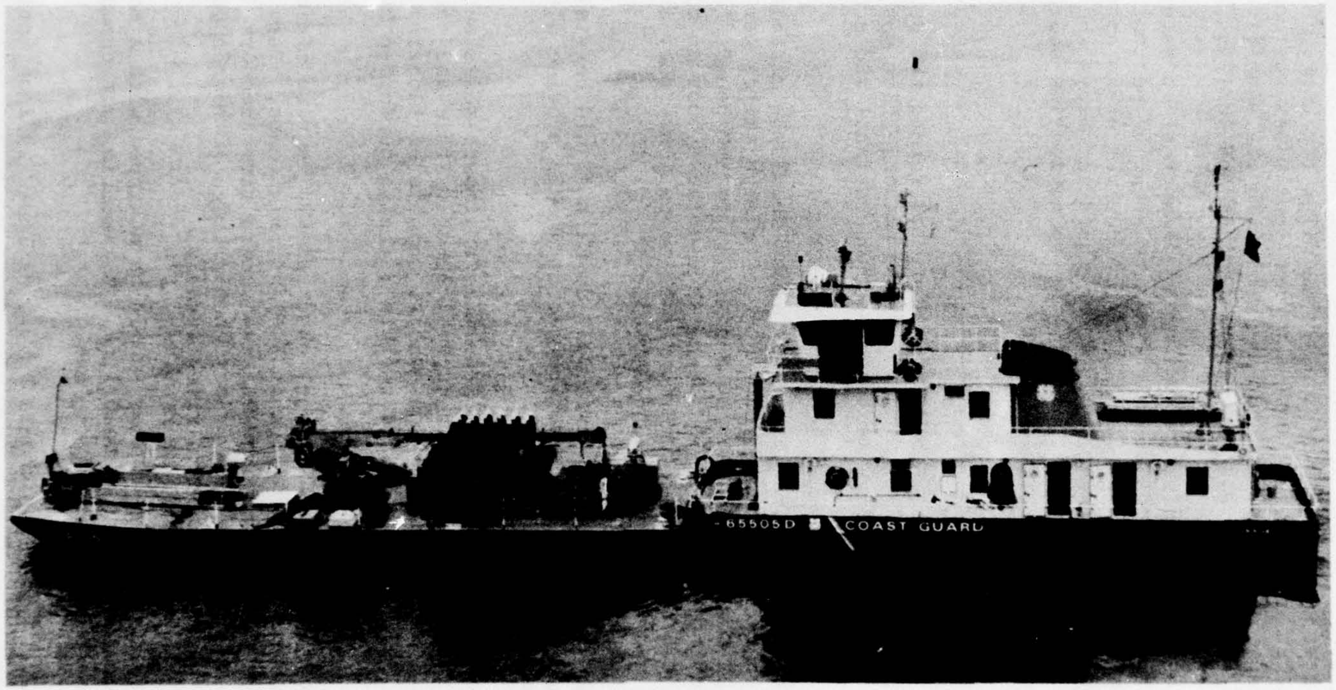



FIGURE 4 - TYPICAL COAST GUARD CUTTER

## 2.0 DEVELOPMENT OF THE CONVENTIONAL BUOY

### 2.1 Wooden Spar Buoys (1874)

In 1767, wooden spar buoys were established in the Delaware River, becoming the first recorded aids to navigation in the history of the United States. These same wooden spar buoys were natural selections for use on the Western Rivers in 1874; however, experience showed that they were not suited to the river environment. Ranging from 20 feet to 70 feet tall, they floated with 7 to 20 feet of freeboard. In high water they were pulled under; in low water they lay across the channel. In both situations, this supposed aid to navigation was in fact an obstacle to safe passage. In addition, the buoys weighed upwards of 1500 pounds, which made them exceedingly difficult to handle and maintain.

### 2.2 Wooden Barrel Buoys (circa 1900)

Wooden barrel buoys replaced the unwieldy wooden spars (Figure 5). Relatively easy to handle and maintain, barrel buoys were in widespread use on the rivers into the 1920's, even though iron buoys had been replacing wooden buoys elsewhere in the nation since 1900. It is probable, however, that the wooden buoys were preferred, because iron buoys, like the wooden spars, were too heavy and unwieldy for river use.

### 2.3 Sheet Metal Buoys (1920)

In the 1920's, lightweight sheet metal buoys, patterned after the iron NUNS and CANS, replaced the wooden barrel buoys on the Western Rivers. By the early 1940's, there were three types of sheet metal buoys in widespread use, their design reflecting the different requirements of an open and pooled river environment (Figure 6).

#### 2.3.1 Type-UM

The pooled river buoys were called Type-UM for Upper Mississippi, a pooled river. They were made in 13 inch, 15 inch, and 19 inch diameters, and weighed between 90 and 210 pounds. They were said to withstand currents up to two miles per hour. In 1943, the buoy cost about $20, and comprised about 42 percent of the buoy population on station.

#### 2.3.2 Type-LM

The open river buoys were called Type-LM for Lower Mississippi River, an open river. The buoy was 18 inches in diameter and weighed only 85 pounds. This buoy contained a significant design modification, which was a rudder that helped to provide lift in swift currents. The rudder design came into use in the 1930's, and it increased the performance capabilities of the buoy from two to four miles per hour. In 1943, the buoy cost less than $10, and comprised about 37 percent of the buoy population on station (Figure 7).

1066

FIGURE 5

A WOODEN BARREL BUOY TOPPED BY SHEET METAL "NUN" CAP. IT IS LIKELY THAT EARLIER VERSIONS OF THE BARREL BUOY DID NOT HAVE THE SHEET METAL TOP, BUT WERE SIMPLY FLAT TOP BARRELS. IN USE CIRCA 1900 TO 1920.

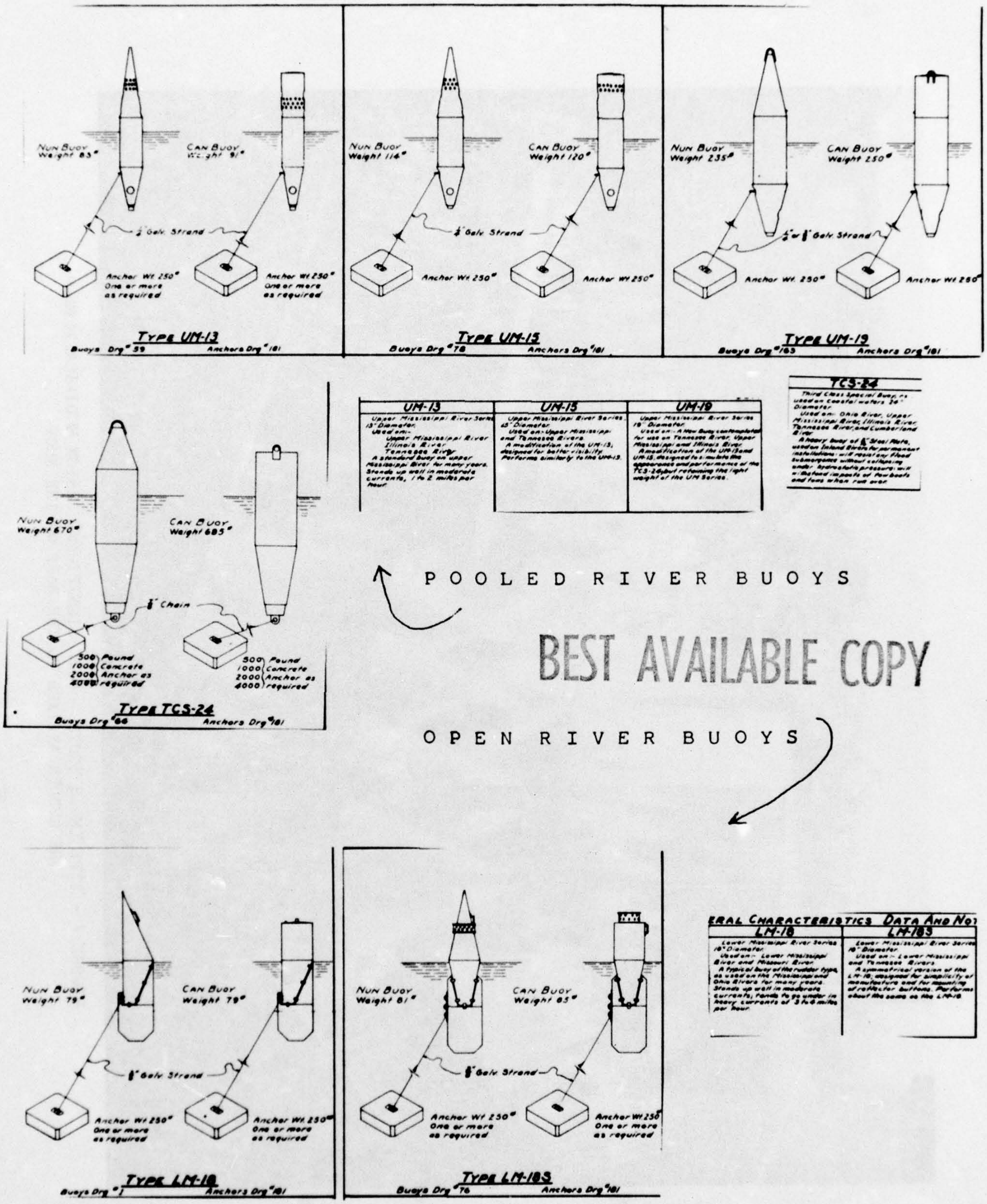




FIGURE 6 - RIVER BUOYS IN USE IN 1941.

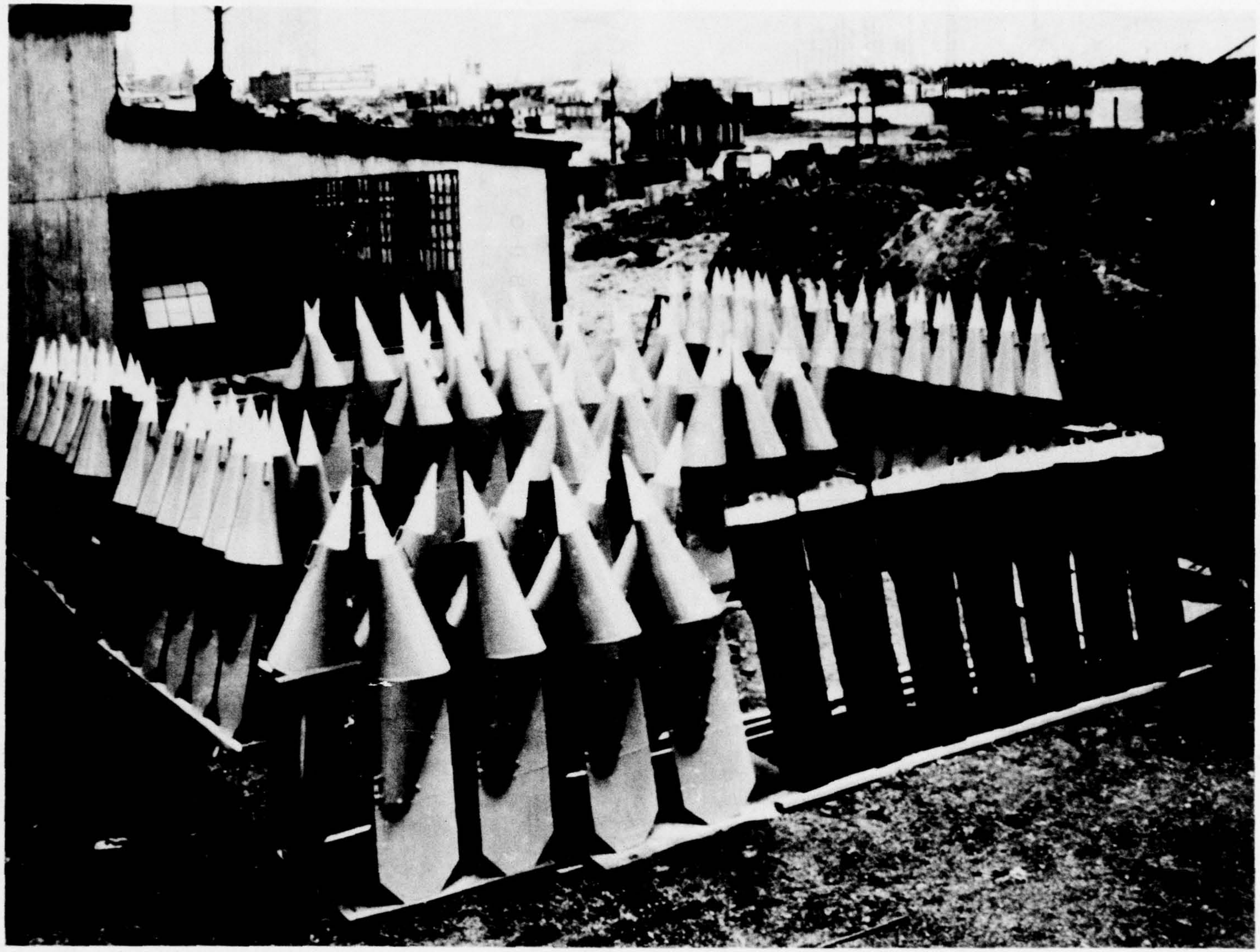


FIGURE 7 - TYPE LM-18 BUOYS. NOTE SIGNIFICANT DESIGN MODIFICATIONS--
THE RUDDER AFFIXED TO THE BASE OF THE BUOY.

2.3.3 Type-TCS

There was another pooled river buoy, called Type-TCS (Third Class Special), significantly more durable than either Type-UM or LM. Twenty-four inches in diameter, the buoy was rudderless and constructed out of 3/16-inch steel plate. It weighed 680 pounds. Its use was centered in the northern areas of the Western Rivers, where winter ice accumulation was a problem. In 1943, the buoy cost $59, and composed about 21 percent of the buoy population on station.

## 2.4 Conventional Radar Buoys (1962)

The need for a buoy with radar reflective qualities in the early 1960's culminated in the design of the 4th class and 6th class buoys presently in use on the Western Rivers. Both radar buoys incorporated the lightweight sheet metal design of the Type-LM and UM, as well as the rudder design of the Type-LM. In addition, the radar buoys were filled with polyurethane foam, which in theory made them unsinkable.

2.4.1 6th Class Buoy (Figure 8)

The 6th class buoy was assigned to pooled rivers because of its tendency to dive in open river currents that approached four miles per hour. The compartmented radar hoods acted as a rudder as the buoy dived, catching water and countering the self-righting tendency of the buoy.

The need for a Missouri River buoy created a design modification to the 6th class radar buoy. Because the 4th class radar buoy was too large for use on the Missouri, and because there was little need for a radar reflective buoy on the narrow river, a 6th class "tall-type" buoy was designed (Figure 9). The "tall-type" was nearly identical in size and weight to the radar type, but it did not have a radar cone. The "tall-type" did not catch water in swift currents, which improved buoy performance to about 4.5 miles per hour.

Presently, a 6th class buoy (radar and "tall-type") costs about $100, and comprises about 50 percent of the buoy population on station.

2.4.2 4th Class Buoy (Figure 10)

The 4th class radar buoy was assigned to open rivers. With more reserve buoyancy than the 6th class buoy, the 4th class buoy begins to dive when currents exceed five miles per hour. As with the 6th class buoy, the compartmented radar hood has a tendency to catch in swift currents, countering the self-righting moments of the buoy.

Presently, a 4th class buoy costs about $200, and comprises about 30 percent of the buoy population on station.

2.4.3 5th Class Buoy (Figure 11)

The 5th class radar buoy is a direct descendent of the Type-TCS. The buoy hull is made of heavier gage steel, it is not foam filled, and it does not have a rudder. Its use is centered in the northern reaches of the Western Rivers, because of ice accumulation.

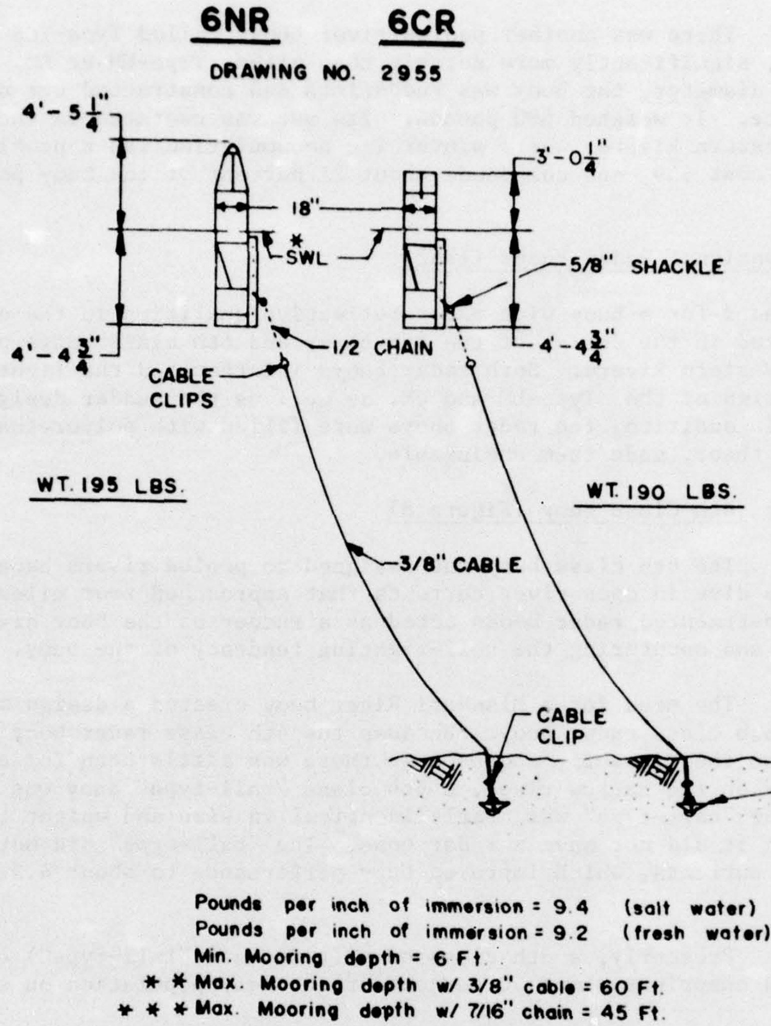



FIGURE 8

THE CONVENTIONAL 6TH-CLASS RADAR BUOY, WHICH REPLACED THE TYPE-UM BUOYS ON POOLED RIVERS IN THE 1960'S. ABLE TO WITHSTAND CURRENTS APPROACHING 4 MILES PER HOUR.

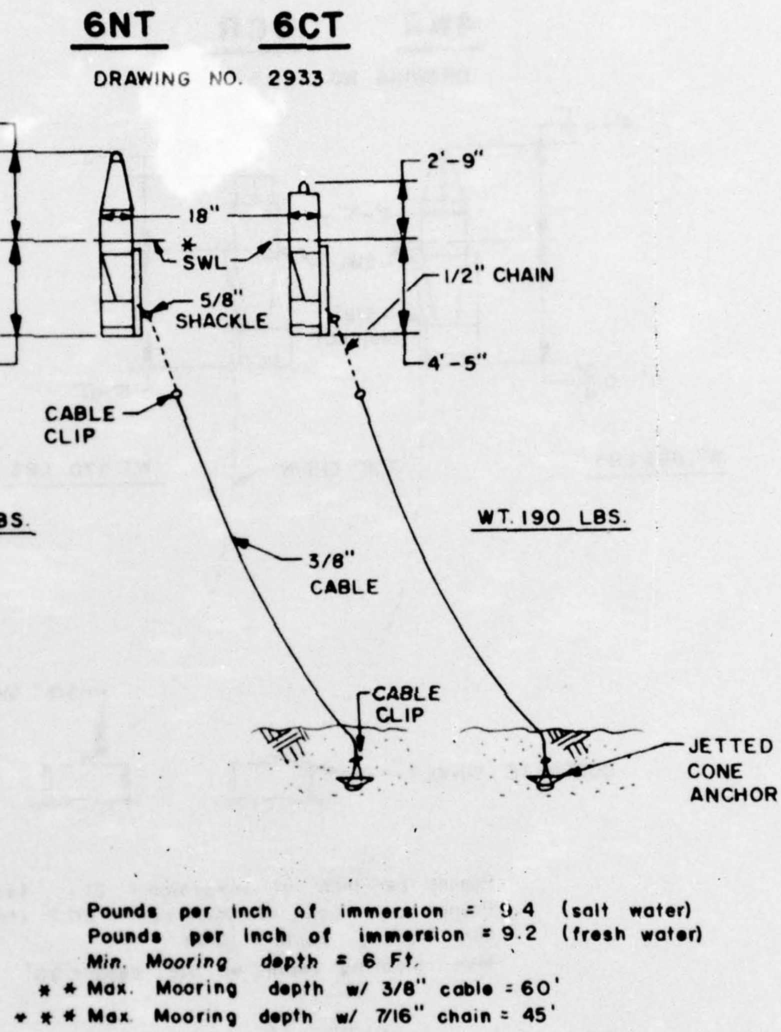
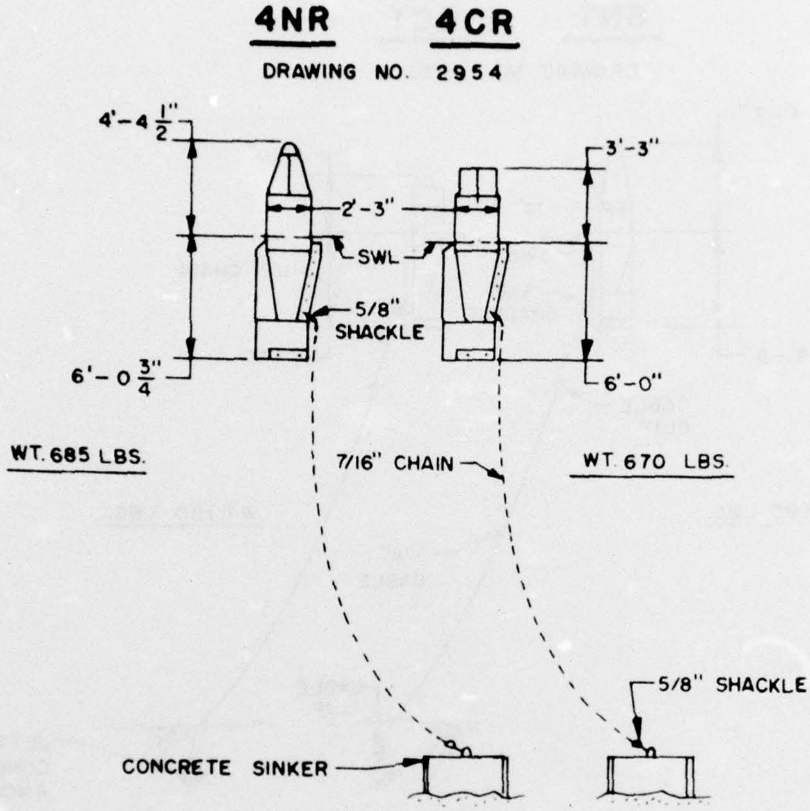



FIGURE 9

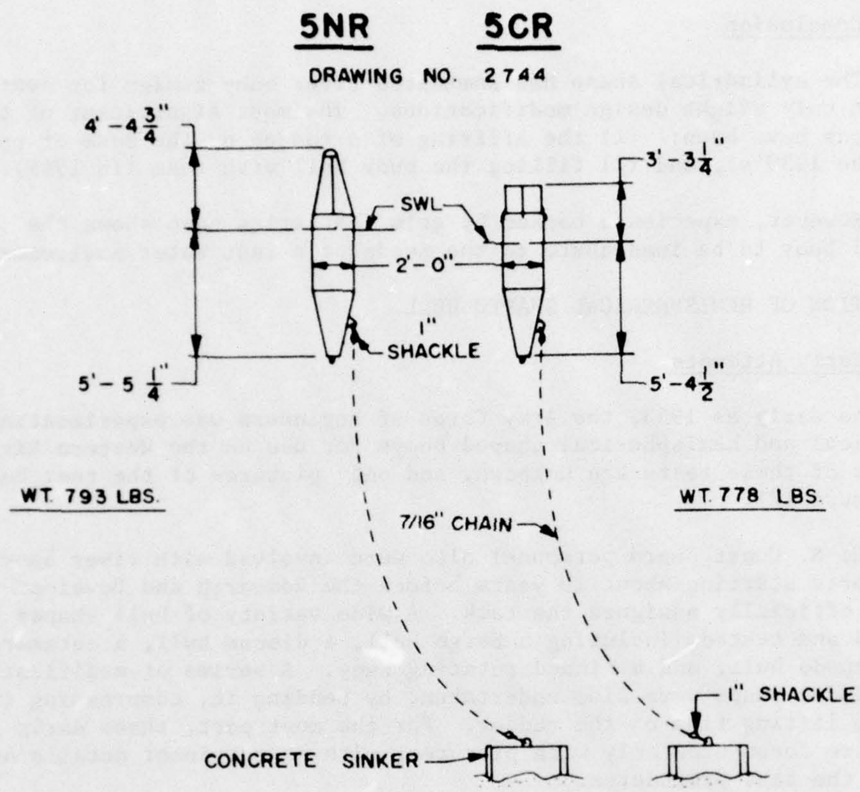
THE CONVENTIONAL 6TH-CLASS TALL (NON-RADAR) BUOY, USED EXCLUSIVELY IN MISSOURI RIVER SINCE THE 1960'S. ABLE TO WITHSTAND CURRENTS APPROACHING 4.5 MILES PER HOUR.




Pounds per inch of immersion = 21.1 (salt water)
Pounds per inch of immersion = 20.7 (fresh water)
Min. Mooring depth = 10 Ft.
Max. Mooring depth w/ 7/16" chain = 90'

FIGURE 10

THE CONVENTIONAL 4TH-CLASS RADAR BUOY, WHICH REPLACED THE TYPE-LM BUOYS ON OPEN RIVERS IN THE 1960'S.
ABLE TO WITHSTAND CURRENTS OF ABOUT 5 MILES PER HOUR.




Pounds per inch of immersion = 16.7 (salt water)
Pounds per inch of immersion = 16.4 (fresh water)
Min. Mooring depth = 6 Ft.
Max. Mooring depth = 60 Ft.

FIGURE 11

THE CONVENTIONAL 5TH-CLASS RADAR BUOY, WHICH IS DIRECT DESCENDENT OF TYPE-TCS. PRESENTLY BEING REPLACED BY 4TH CLASS RADAR BUOY.

Presently, the 5th class radar buoy costs over $300, and comprises about 20 percent of the buoy population on station. It is being replaced by 4th class radar buoys because of its high cost.

### 2.5 Conclusion

The cylindrical shape has dominated river buoy design for over 100 years, with only slight design modifications. The most significant of these modifications have been: (1) the affixing of a rudder on the base of the buoy (in the 1930's), and (2) filling the buoy hull with foam (in 1969).

However, experience backed by grim statistics have shown the cylindrical buoy to be inadequate to the needs of a fast water environment.

## 3.0 SELECTION OF HEMISPHERICAL SHAPED HULL

### 3.1 Early Attempts

As early as 1953, the Army Corps of Engineers was experimenting with spherical and hemispherical shaped buoys for use on the Western Rivers. The results of these tests are unknown, and only pictures of the test buoys remain (Figure 12).

U. S. Coast Guard personnel also were involved with river buoy design efforts starting about 10 years before the Research and Development Center was officially assigned the task. A wide variety of hull shapes were constructed and tested, including a barge hull, a discus hull, a catamaran hull, a torpedo hull, and a finned rotating buoy. A series of modifications to the cylinder shape were also undertaken, by bending it, compressing it, and placing lifting fins on the rudder. For the most part, these early attempts were documented only with pictures, with no pertinent details and results of the test procedures.

Appendix A illustrates the types of hulls tested by field personnel before the Research and Development Center became involved in the design of a Fast Water Buoy.

### 3.2 Design Study Group

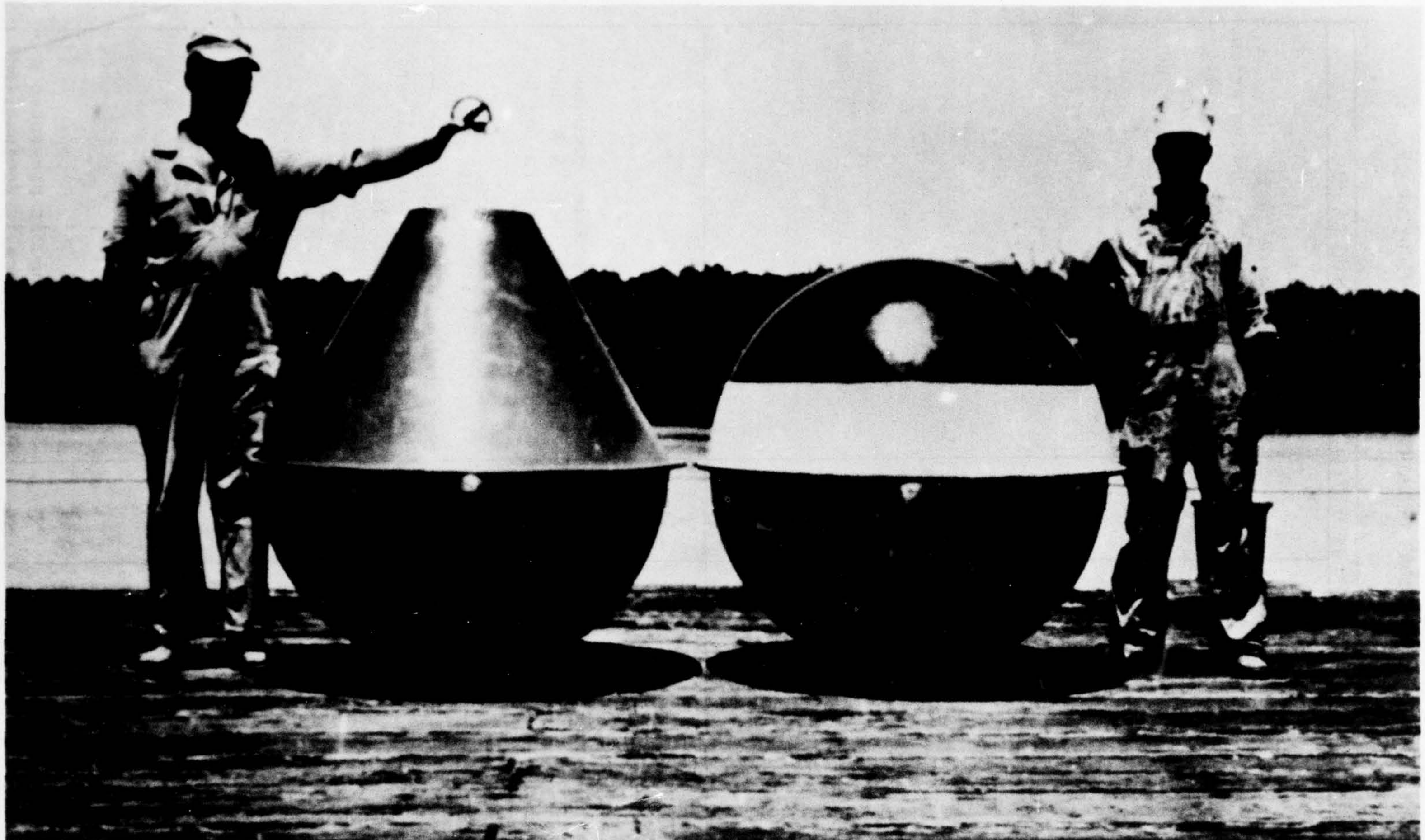
Early in 1972, the Office of Research and Development formed a Design Study Group. The Group's objective was to identify hull shapes that could meet the operational requirements of a Fast Water Buoy.

The Group proposed fourteen hull shapes, which fell into four broad categories (Figure 13)--Boat Shapes, Spherical Shapes, Cylindrical Shapes, and a varied assortment of "others." On the basis of known design objectives, eight of the initial fourteen hulls were rejected without field testing.

The six configurations that survived the initial design discussions were:

1. Barge Type Hull (with and without a deep keel)

2. Hemispherical Hull



VICKSBURG DISTRICT CORPS OF ENGINEERS, U. S. ARMY
BUOYS. Plastic reinforced with fiber glass. Cone buoy on left has 48" hemispherical bottom and 36" conical top. Volume - 29.3 cubic feet; weight - 115 pounds, which includes 45 pounds counter weight. Spherical buoy on right is 48" sphere. Volume - 33.5 cubic feet; weight - 100 pounds, which includes 27 pounds counter weight.
29 May 1953 File A7/826

FIGURE 12 - EARLY EXPERIMENTATION WITH SPHERICAL/HEMISPHERICAL SHAPE BY CORPS OF ENGINEERS. RESULTS OF TESTS UNKNOWN.

FIGURE 13 - HULL CONFIGURATIONS PROPOSED BY DESIGN STUDY GROUP

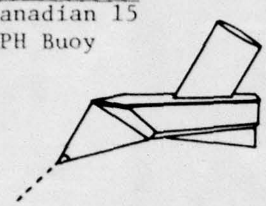
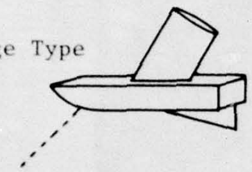
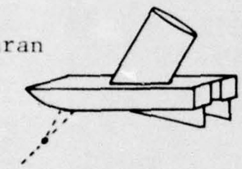
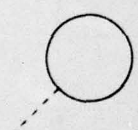
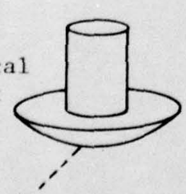
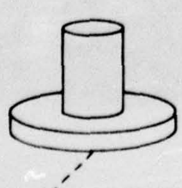
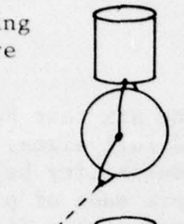
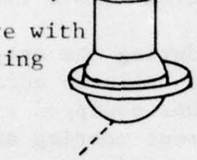
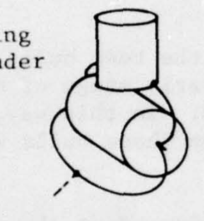
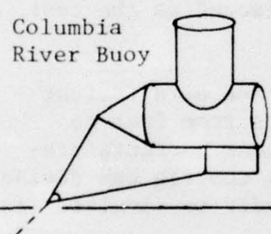
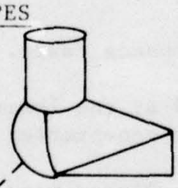
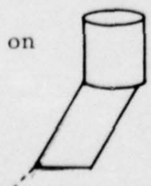
| CONFIGURATION | ACCEPTED | REJECTED | REMARKS |
|---|---|---|---|
| 1. BOAT SHAPES | | | |
| Canadian 15 MPH Buoy  | | X | While there were basic differences in the configuration, the "boat" shape was essentially the same. For ease in proto-type construction, the BARGE HULL was selected. |
| Barge Type  | X | | |
| Catamaran  | | X | |
| 2. SPHERICAL SHAPES | | | |
| Sphere  | | X | Shape not acceptable, because of need for distinct "NUN" and "CAN" shapes atop floating hull. |
| Hemisphere  | X | | Selected to obtain data on spherical shapes over greatest possible range of drafts. |
| Small Spherical Segment  | X | | |
| Discus  | X | | Selected because it presented a planning surface in conjunction with spherical hull. |

FIGURE 13 continued

| CONFIGURATION | ACCEPTED | REJECTED | REMARKS |
|---|---|---|---|
| 2. SPHERICAL SHAPES (cont.) | | | |
| Rolling Sphere  | | X | Rejected because it is too dependent upon moving parts that would be easily fouled in river environment. |
| Sphere with floating ring  | | X | Same as spherical buoy as far as underwater shape is concerned; also, too dependent upon moving parts. |
| 3. CYLINDRICAL SHAPES | | | |
| Rolling Cylinder  | | X | Too dependent upon moving parts. |
| Columbia River Buoy  | | X | Previously tested, with known performance data. |
| 4. OTHER SHAPES | | | |
| Teardrop  | X | | Unique and untested. |
| 5th Class Plastic  | X | | Untested in river environment. |
| Plank on Edge  | | X | Configuration is essentially a planning surface with a deep mooring point. Discus and Barge to be outfitted with deep keels to test the concept. |

3. Small Spherical Segment

4. Discus Hull

5. Teardrop

6. 5th Class Plastic (Cylindrical)

Figure 14 shows the design sketches of four of the six test hulls. The hulls were constructed by Coast Guard personnel in half and full sizes. There was no effort made during construction to provide strength or durability beyond that needed for the tests. For the most part, the test hulls were made of plywood and pine strip frames, filled with polyurethane form, and covered with a fiberglass skin.

The hulls were constructed to allow variations during the anticipated performance tests. Compartments were built into the hulls to accommodate lead weights used to vary displacement. Also, each buoy was equipped with several mooring positions to discover the effect of different mooring angles on hull performance.

### 3.3 Field Evaluation

The purpose of field evaluation was to subject the test hulls to a range of current velocities, and thus screen out at any early stage of development those hulls whose performances were not acceptable. In this way, research attention would focus at an early stage only upon those hulls with the highest potential for success.

The Upper Mississippi River at St. Louis was selected as the test site. Here, open river conditions prevailed.

The test plan called for observing hull performance at different river depths and mooring positions over a range of currents from four to eight miles per hour. Unfortunately, only four mile per hour currents prevailed at the test site during the evaluation period, so a tow rig was devised that permitted towing the test hulls alongside a river tender to simulate six and eight mile per hour currents.

Appendix B details the results of the performance tests.

It became obvious during the tests conducted at the lower end of the current scale that four of the test hulls were not acceptable:

1. Both the Half-Scale Barge and Half-Scale Discus were too small. Both floundered in four mile per hour currents.

2. At four miles per hour, the Spherical Segment Hull created mooring loads that ranged from 35 pounds to 125 pounds, depending upon the mooring position. But even at 35 pounds tension, the buoy trimmed aft with the current, with its afterdeck awash. As the mooring load increased, performance deteriorated, and the hull eventually dived.

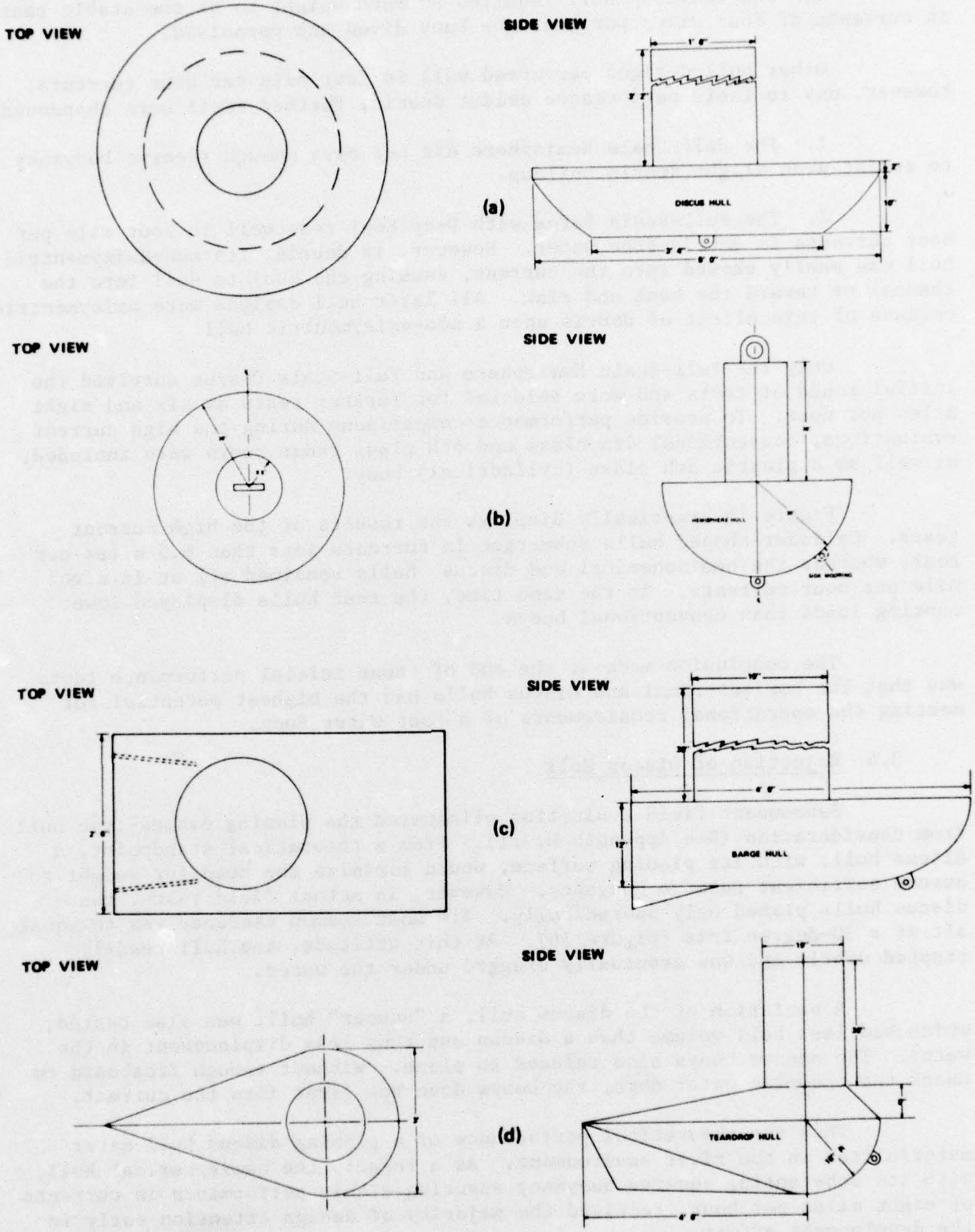



FIGURE 14 - TEST HULLS

3. The Teardrop Hull required so much weight to become stable that in currents of four miles per hour the buoy dived and porpoised.

Other hull designs performed well in four mile per hour currents; however, due to their performance amidst debris, further tests were abandoned:

1. The Half-Scale Hemisphere did not have enough reserve buoyancy to resist even slight debris buildup.

2. The Full-Scale Barge with Deep Keel rode well in four mile per hour currents in debris-free water. However, in debris, its non-axisymentric hull was easily skewed into the current, causing the buoy to sail into the channel or toward the bank and sink. All later hull designs were axisymentric because of this effect of debris upon a non-axisymentric hull.

Only the Full-Scale Hemisphere and Full-Scale Discus survived the initial round of tests and were selected for further tests at six and eight miles per hour. To provide performance comparisons during the high current evaluations, conventional 4th class and 6th class radar buoys were included, as well as a plastic 5th class (cylindrical) buoy.

Figure 15 graphically displays the results of the high current tests. Cylinder-shaped hulls submerged in currents less than 6.5 miles per hour, whereas the hemispherical and discus hulls remained afloat in eight mile per hour currents. At the same time, the test hulls displayed lower mooring loads than conventional buoys.

The conclusion made at the end of these initial performance tests was that the hemispherical and discus hulls had the highest potential for meeting the operational requirements of a Fast Water Buoy.

### 3.4 Rejection of Discus Hull

Subsequent field evaluation eliminated the planing discus-type hull from consideration (See Appendix D.3.1). From a theoretical standpoint, a discus hull, with its planing surface, would minimize the need for weight to assure sufficient reserve buoyancy. However, in actual field tests, the discus hulls planed only sporadically. Its most common tendency was to squat aft at a 30-degree trim (Figure 16). At this attitude, the hull readily trapped debris and was eventually dragged under the water.

A variation of the discus hull, a "saucer" hull, was also tested, which had less hull volume than a discus and thus less displacement in the water. The saucer buoys also refused to plane. Without enough freeboard to knock the oncoming water down, the buoys dove bow first into the current.

Thus the theoretical performance of a planing discus hull never materialized in the river environment. As a result, the hemispherical hull, with its substantial reserve buoyancy assuring stable performance in currents of eight miles per hour, received the majority of design attention early in the development effort.

FIGURE 15

RESULTS OF HIGH CURRENT TESTS

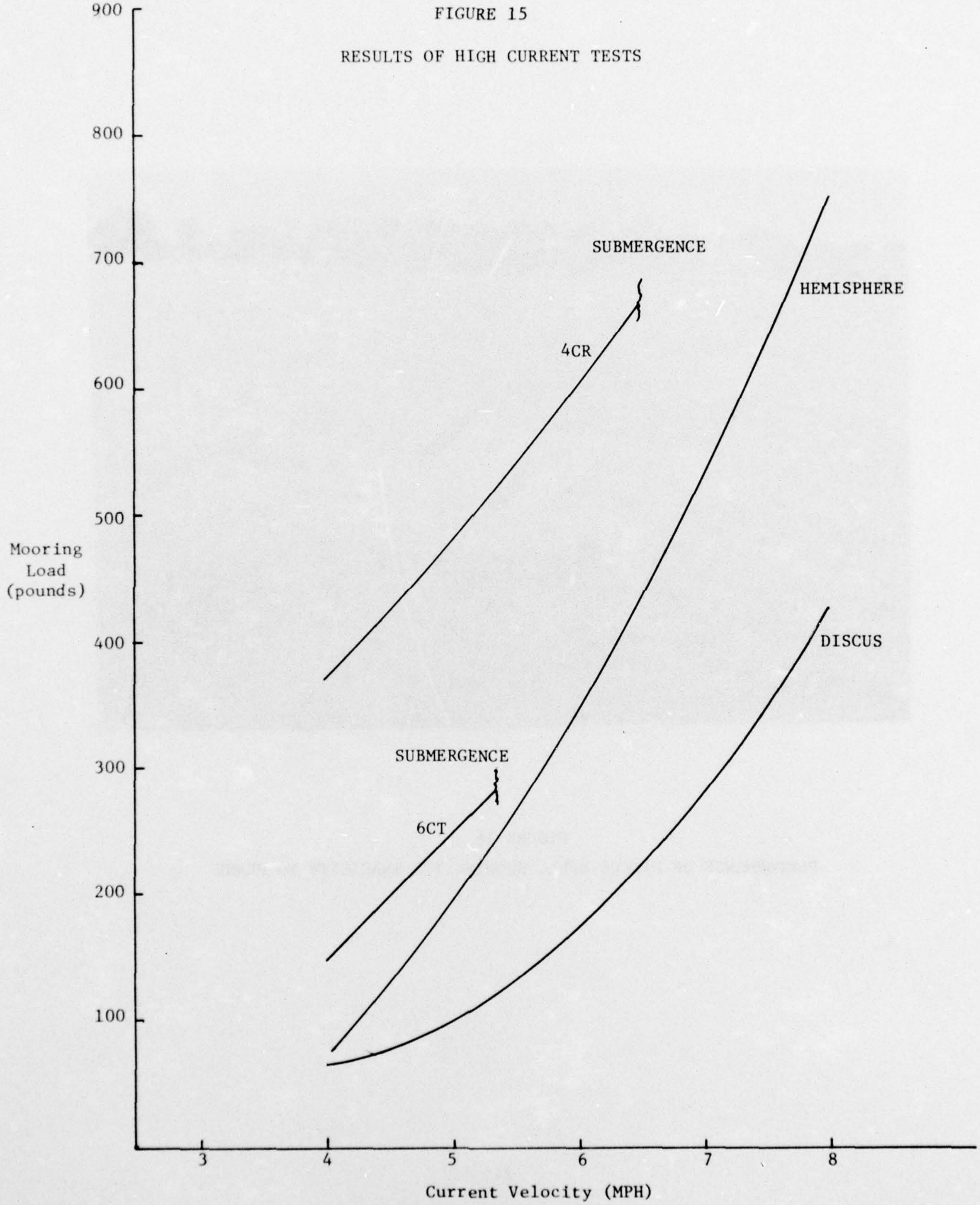



FIGURE 16

PERFORMANCE OF DISCUS HULL, SHOWING ITS INABILITY TO PLANE

## 4.0 BUOY PERFORMANCE COMPUTER MODEL

### 4.1 Development

A computer model of the river environment was designed at the Coast Guard Academy. Appendix C details the computer program and its underlying assumptions.

The model treated the river environment as a hypothetical fluid dynamic system, and the buoy as a body suspended in steady state equilibrium in that system. A desired river condition could be created by inputing depth of water, the velocity of surface and subsurface currents, and the volume of debris present. A buoy then could be "established" in this hypothetical environment by inputing buoy shape and weight, as well as length and type of mooring. The model would then output predicted mooring load and available daymark area, either in a printout format or graphically. With the model, theoretical buoy performance could be ascertained.

### 4.2 Verifying the Model

To check the validity of the model's predictions against real world measurements, a series of carefully controlled tests were conducted in the tidal estuary of the Piscataqua River, off Dover Point, New Hampshire. The Piscataqua River site was selected because the semi-diurnal ebb and flood of the tide produced a range of currents between zero to six knots in close, predictable succession.

An array of test buoys was established which included a standard 4th and 6th class buoy, 3 foot and 4 foot hemispherical test buoys (see Section 5.0), a 3-foot diameter sphere, and a 4-foot and 5-foot diameter discus hull. Mooring load cells were attached in line with the moorings, and a current meter was used to measure the current velocity alongside each buoy. A visual record was made with slides and movies.

The tests revealed the following shortcomings in the computer model:

1. The math model is a steady state simulation that does not account for the effects of wind and waves upon buoy performance. The test results indicated that the effect of wind and waves is significant. Recorded mooring tension is actually a time varying range of mooring tensions, which varies by two to three times the minimum observed tension, depending upon the wind and wave forces.

2. The model consistently underestimated the mooring forces at current velocities in excess of three knots.

Appendix D details the results of the Piscataqua River tests.

While being somewhat inaccurate quantitatively, the model did accurately predict the comparative performance of different buoy hulls in regard to daymark area, mooring loads, and resistance to debris accumulation.

4.3 Simplified Computer Model

The computer model was eventually simplified and placed on a programmable hand calculator. Appendix E contains the simplified program.

In this format, the computer model proved to be invaluable and greatly expedited prototype design (see Section 7.0).

# 5.0 HEMISPHERICAL TEST BUOYS

## 5.1 Design

In mid-1974, the design objective shifted from hull selection to test buoy construction. The hemispherical hull had proved itself to be the shape most suited for meeting the operational requirements. With the emphasis being placed on what to build, rather than on how to build it, two major design decisions were made.

1. Test Buoy Size: Initially, a 3-foot diameter and 4-foot diameter hull were fabricated. The major advantage of increased buoy size was not buoy visibility, for freeboard was increased by only six inches by a one-foot expansion in the diameter of the buoy. Rather, it was the reserve buoyancy of the larger buoy that increased significantly, from 610 pounds in the 3-foot version to 1370 pounds in the 4-foot variety. The range of buoyancy in the hemispherical test buoys also straddled the existing reserve buoyancy of the 4th class radar buoy (740 pounds).

2. Hull Material: Two materials were considered, steel and plastic. Both were conformable to large scale, mass production. However, at the time of selection, steel had certain disadvantages; among them were (1) uncertain, limited supply; (2) equally uncertain cost, which had been mounting rapidly; (3) an anticipated long lead time; and (4) weight, which was twice that of a comparable plastic buoy. The decision was made to construct the hemispherical test buoys out of readily available 1/4-inch thick thermoformed ABS plastic shells.

## 5.2 Construction

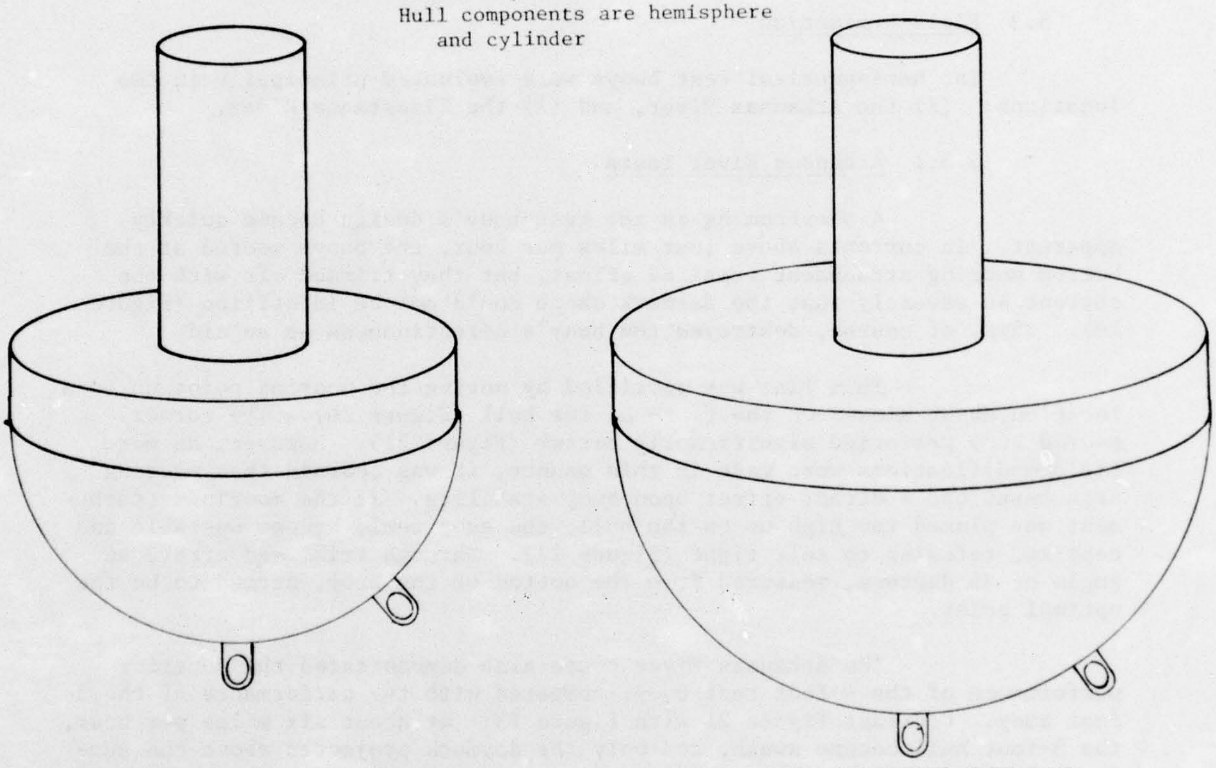
Figure 17 shows the 3-foot and 4-foot hemispherical test buoys.

Made of 1/4-inch thick thermoformed ABS plastic shells, the buoys were 3-foot and 4-foot hemispherical sections topped with a 1/2-foot high cylindrical section that was solvent welded to the bottom. The purpose of this design was to provide greater freeboard without extending the diameter of the buoy.

For ballast, 20 pounds of concrete was molded into the bottom of the hull. The remainder of the shell was filled with two pounds per cubic foot polyurethane foam for buoyancy to meet the operational requirement for an "unsinkable" buoy. A 1/2-inch mooring eye was fixed to the bottom of the buoy, bolted through the hull and concrete ballast for added strength. Two lifting eyes were provided at the top of the buoy hull, bolted through the plastic shell with reinforcing plastic pads. The buoys were painted red or black.

TEST BUOYS

1/4 inch ABS plastic shell
Polyurathane foam filled hulls
20 pounds concrete ballast
0° and 36° mooring eyes
Hollow daymarks
Hull components are hemisphere
and cylinder



3 FOOT (DIAMETER) TEST BUOY
88 POUNDS

4 FOOT (DIAMETER) TEST BUOY
135 POUNDS

FIGURE 17

TEST BUOYS

NOTE, CORNER MOORING WAS A LATER DESIGN MODIFICATION.

As these were only test buoys, no attempt was made to equip the buoys with a daymark meeting the operational requirements. Small "dunce cap" road cans were screwed into the top of the nuns, while truncated 5-gallon water containers simulated the can shape.

The 3-foot test buoy weighed about 90 pounds. The 4-foot test buoy weighed about 135 pounds. The 3-foot test buoy cost $165; the 4-foot buoy cost $200. Both prices are based upon production of about 100 buoys.

Figure 18 compares the two test buoys with 4th class and 6th class buoys. As Figure 18 shows, the hemispherical test buoys were lighter, cheaper, and contained more reserve buoyancy than their cylindrical counterparts.

### 5.3 Field Evaluation

The hemispherical test buoys were evaluated principally in two locations: (1) the Arkansas River, and (2) the Piscataqua River.

#### 5.3.1 Arkansas River Tests

A shortcoming in the test buoy's design became quickly apparent. In currents above four miles per hour, the buoys moored at the bottom mooring attachment remained afloat, but they trimmed aft with the current so severely that the daymark shape could not be identified (Figure 19). This, of course, destroyed the buoy's effectiveness as an aid.

This flaw was rectified by moving the mooring point up to a location about midway on the flare of the hull (Figure 20). The corner moored buoy performed significantly better (Figure 21). However, as more field modifications were made in this manner, it was learned that mooring attachment had a direct effect upon buoy stability. If the mooring attachment was placed too high up on the hull, the buoy would become unstable and capsize, refusing to self right (Figure 22). Through trial and error, an angle of 36 degrees, measured from the bottom of the buoy, seemed to be the optimal point.

The Arkansas River tests also demonstrated the superior performance of the 4-foot test buoy, compared with the performance of the 3-foot buoy. Contrast Figure 21 with Figure 23: at about six miles per hour, the 3-foot hull became awash, and only the daymark projected above the surface of the water; however, the 4-foot test buoy remained above the surface even in 8 mile per hour currents (estimated), with a head wave only occasionally washing over the top of the hull. At this current velocity, any cylindrical buoy would be completely submerged.

#### 5.3.2 Piscataqua River Tests

The performance of the test buoys observed on the Arkansas River was confirmed by the Piscataqua River tests. The 3-foot and 4-foot hemispherical test buoys remained persistently afloat under all conditions (Figure 24). Even in 2-foot waves generated by 35 knot winds, the hemispheres surfed against the current, sloughing off the waves by spinning. The bottom moored buoys did ride with a 45 degree trim aft, but the corner moored buoys rode upright.

FIGURE 18

COMPARISON OF TEST BUOYS WITH CONVENTIONAL BUOYS

Synopsis of Fast Water Buoy Characteristics

| | 4TH CLASS | | 6TH CLASS | | 4-FOOT HEMISPHERE | | 3-FOOT HEMISPHERE | |
|---|---|---|---|---|---|---|---|---|
| Characteristics | NUN | CAN | NUN | CAN | 18 gage steel | ABS | 18 gage steel | ABS |
| Weight (lbs) | 500 | 485 | 165 | 160 | 200 | 125 | 140 | 90 |
| Maximum Diameter (ft) | 2-1/4 | 2-1/4 | 1-1/2 | 1-1/2 | 4 | 4 | 3 | 3 |
| Overall Height (ft) | 10-1/2 | 9-1/4 | 8-3/4 | 7-1/2 | 5-1/4 | 5-1/4 | 4-3/4 | 4-3/4 |
| Reserve Buoyancy (lbs-still water) | 736 | 745 | 257 | 262 | 875 | 950 | 310 | 360 |
| Waterline to Top of Daymark (ft-still water) | 5 | 4-1/3 | 4-1/4 | 4-1/4 | 4 | 4 | 4 | 4 |
| Price Per Buoy ($) | 233 | 233 | 105 | 105 | | Estimate $200 | | Estimate $165 |

FIGURE 19

Center moored three-foot hemispherical buoy. Arkansas River mile 70.4 in flows of 156,000 cfs (approx. 6 mph).

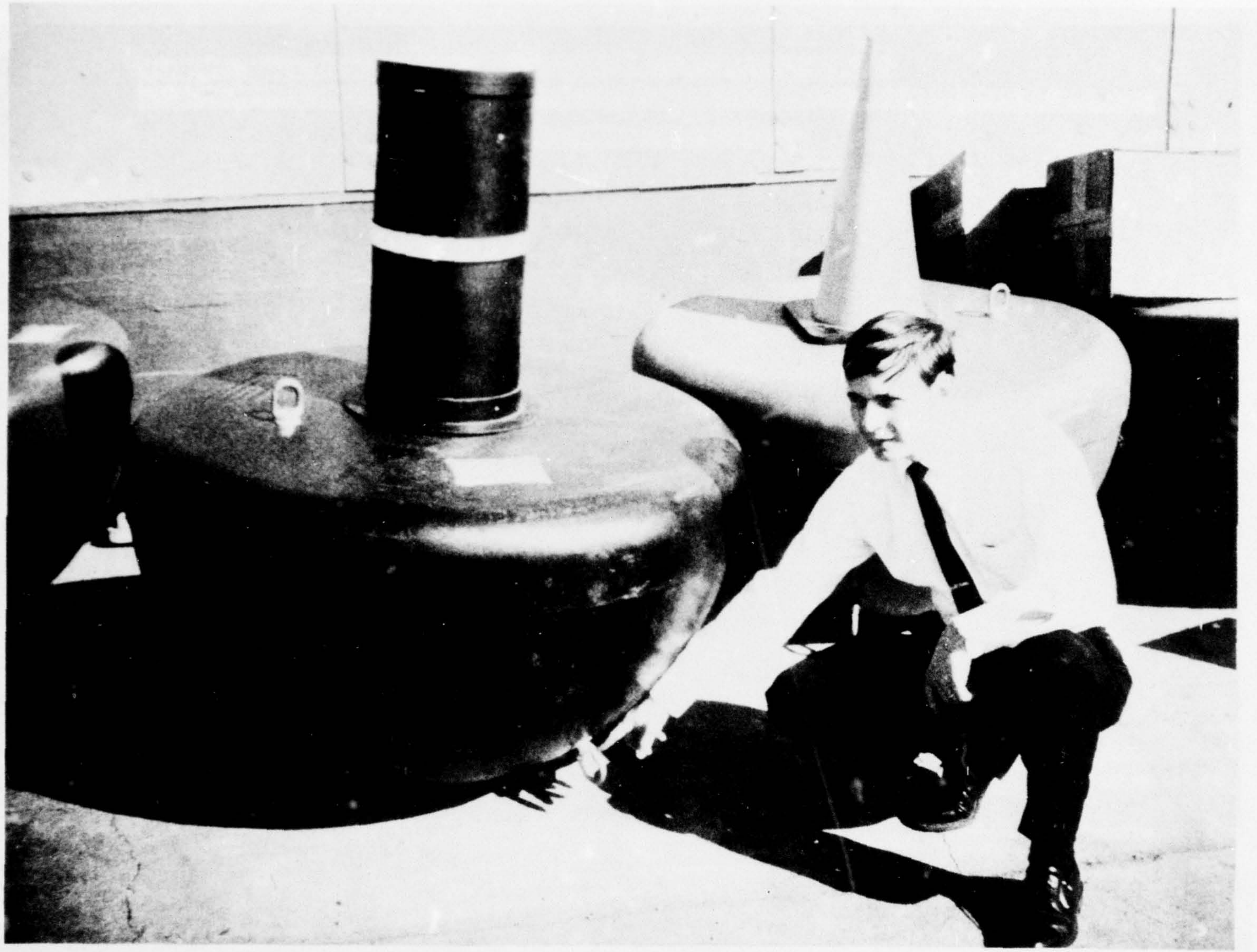


FIGURE 20 - DESIGN MODIFICATION IN TEST BUOYS--SIDE MOORING ATTACHMENT

FIGURE 21

Side moored three-foot hemispherical buoy (side mooring at 360° from axis of buoy). Arkansas River mile 70.4 in flows of 156,000 cfs (approx. 6 mph).

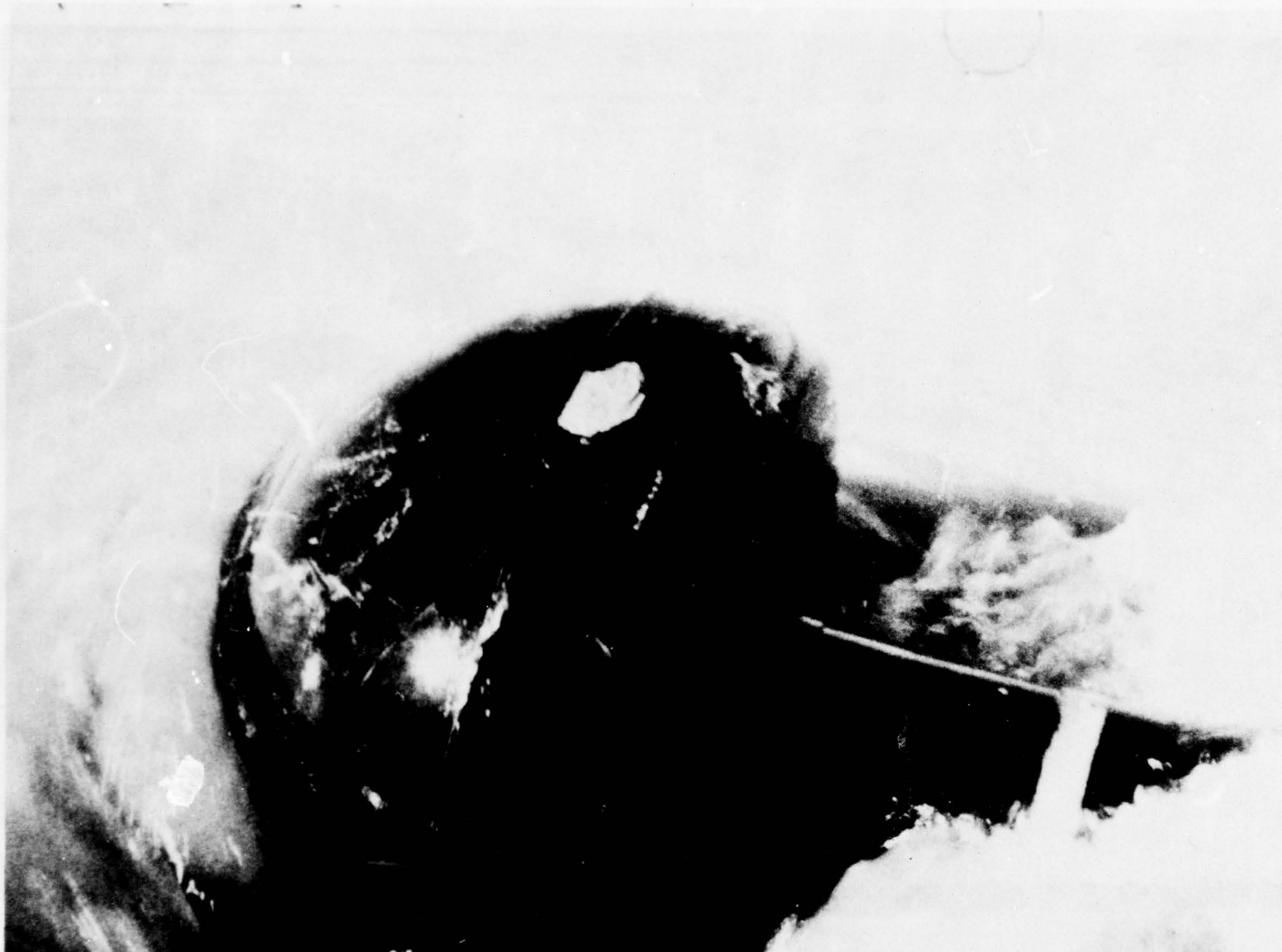


FIGURE 22

Side moored three-foot hemispherical buoy (side mooring at 45° from axis of the buoy).

At 36° the buoy was self righting but at 45° the buoy stayed overturned.

FIGURE 23

Side moored four-foot hemispherical buoy (side moored at 36°). No apparent debris

Mooring: 60 ft. 3/8" cable Arkansas River mile 71.0

Flow rate: 180,000 cfs (approx. 8 mph)

By comparison, the 4th class and 6th class buoys displayed significantly inferior performance under the same conditions (Figure 25). At a scope of 3.3:1 and below, the 6th class buoy became completely submerged at currents of four miles per hour. Increasing the scope lifted the upper 5 percent of the buoy out of the water, but the aid remained inadequate. While the 4th class radar buoy never completely submerged, it leaned hard over on its side in 4.6 miles per hour currents, reducing daymark visibility. (The 4th class buoy was not tested at a scope less than 3.3:1 due to severe weather conditions preventing its deployment.) At 5.7 miles per hour, about 60 percent of the 4th class buoy was beneath the water. Wind and wind-driven waves only deteriorated performance of the conventional buoys. Unlike the hemispherical test buoys, which twist and spin in the waves, the cylinder buoys met each wave head-on, which only increased the possibility for submergence.

### 5.4 Collision Tests

Controlled collison tests were conducted on the 3-foot and 4-foot hemispherical test buoys. The purpose of the tests was to determine whether the test buoys could withstand towboat collison and return to normal operation.

Each test consisted of two types of collisions. In the first, a river tender's barge drifted upon the buoy perpendicular to the current; in the second, the barge ran head-on into the buoy.

The results were consistent with known performance traits of the hemispherical buoys. Whereas conventional buoys are dragged underwater by collision, the test buoys struggled to remain afloat. The test buoys' reaction to the collision was to slide alongside the barge, the force of collision causing them to drag their sinkers until either the mooring failed or the barge drifted away (Figure 26). With this type of reaction to collision, the daymark was particularly susceptible to serious damage, especially during head-on collisons. Also, the tests pointed to the requirement for a rugged mooring attachment on the hemispherical buoy, for it was the mooring attachment that bore the brunt of towboat collision.

### 5.5 Flaws in Test Buoy Design

However promising the test buoys' performances were, four design modifications were indicated:

1. Buoy Size: As discussed in Section 5.3.1 above, the 3-foot hemispherical buoy, with its reserve buoyancy of 610 pounds, was not large enough. In high current flows, the hemispherical shape generated a head wave. This head wave would wash over the hull of the 3-foot test buoy, reducing the visible area of the buoy body, as well as concentrating the forces generated by the current flow upon the daymark itself. The 4-foot hemispherical test buoy had sufficient reserve buoyancy (1370 pounds) to withstand the head wave, keeping the top of the buoy hull relatively free of water, and maximizing the total visibility of the daymark and buoy body.

FIGURE 24 - THREE AND FOUR-FOOT HEMISPHERICAL TEST BUOYS IN PISCATUQUA RIVER

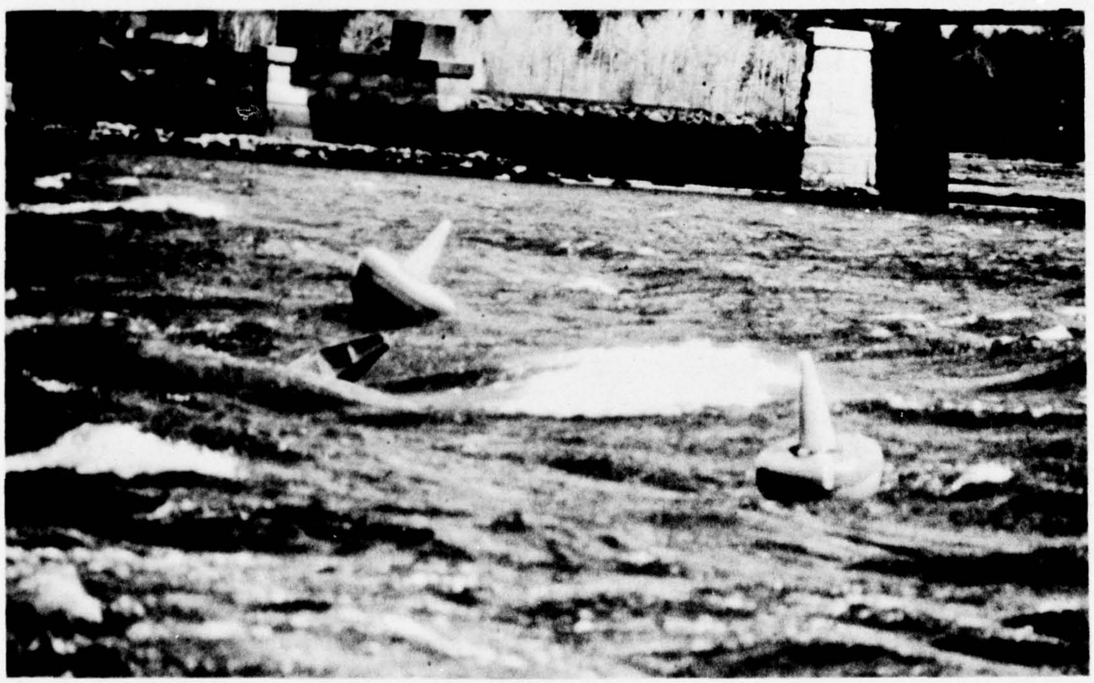


FIGURE 25 - COMPARISON OF TEST BUOYS WITH CONVENTIONAL BUOY DURING PISCATAQUA RIVER TESTS. NOTE SUPERIOR VISIBILITY OF TEST HULLS.

FIGURE 26

FOUR-FOOT TEST BUOY DURING COLLISION. BUOY REFUSES TO SUBMERGE, BUT SLIDES ALONGSIDE RAKE OF BARGE, DRAGGING SINKER OR PARTING MOORING.

2. Mooring Angle: As described in Section 4.3.1 above, a mooring eye located at the base of the buoy hull caused the buoy to trim against high current flows, significantly reducing the visibility of the daymark. This trait was corrected by moving the mooring eye up the hull, with a 36 degree angle measured from the bottom of the buoy being the optimal location, assuring upright performance and overall buoy stability.

3. Mooring Strength: During the field evaluations, frequent failures of the mooring eye were experienced, caused by the mooring eye pulling out of the hull (Figure 27). It was apparent from these failures that the method of anchoring the mooring eye in the hull was not adequate in the hemispherical test hulls. Instead of plastic reinforcing pads at the point of mooring eye attachment, a through-bolt design was necessary to provide adequate mooring eye durability and strength.

4. Hull Material: The ABS plastic was not an acceptable hull material. Damage sustained by the buoys proved the plastic to be quite brittle, and the hull would crack and break away in pieces upon impact (Figure 28). ABS plastic was also sensitive to temperature changes; as the temperature dropped, the brittleness of the plastic increased. While minor cracks and holes in the hull could be repaired by field personnel using PVC glue, commonly experienced large holes caused by the shattering of the brittle hull were beyond the capability of field personnel to repair. As a result, most damaged hulls had to be scrapped.

## 6.0 DEBRIS

### 6.1 Scope

The accumulation of debris is a persistent problem in the Western Rivers environment, which is exaggerated by the hemispherical hull design.

The term "debris" describes a wide variety of vegetation and other organic material, large and small, carried in the current flows. The sources of debris are the river banks, which for the most part are overgrown with plants and trees. During high water or fast current periods, the river banks may be eroded, causing the vegetation to fall into the river and be swept downstream. Debris exists throughout the Western Rivers System, but its heaviest concentrations are found in the open rivers, where fluctuating river levels and erosion continuously draw river bank material into the current flow.

### 6.2 The Effect of Debris

Generally, debris has two effects upon a floating aid:

1. The smaller types of debris, which consists of small roots, blades of grass, and weeds between six inches and three feet in length, all with very thin diameters, collect upon the mooring cable (Figure 29). This material, known as "mill grass," actually weaves itself upon the mooring line, causing a large thatch that must be axed off by servicing personnel. The accumulation of "mill grass" increases mooring tension and buoy drag.

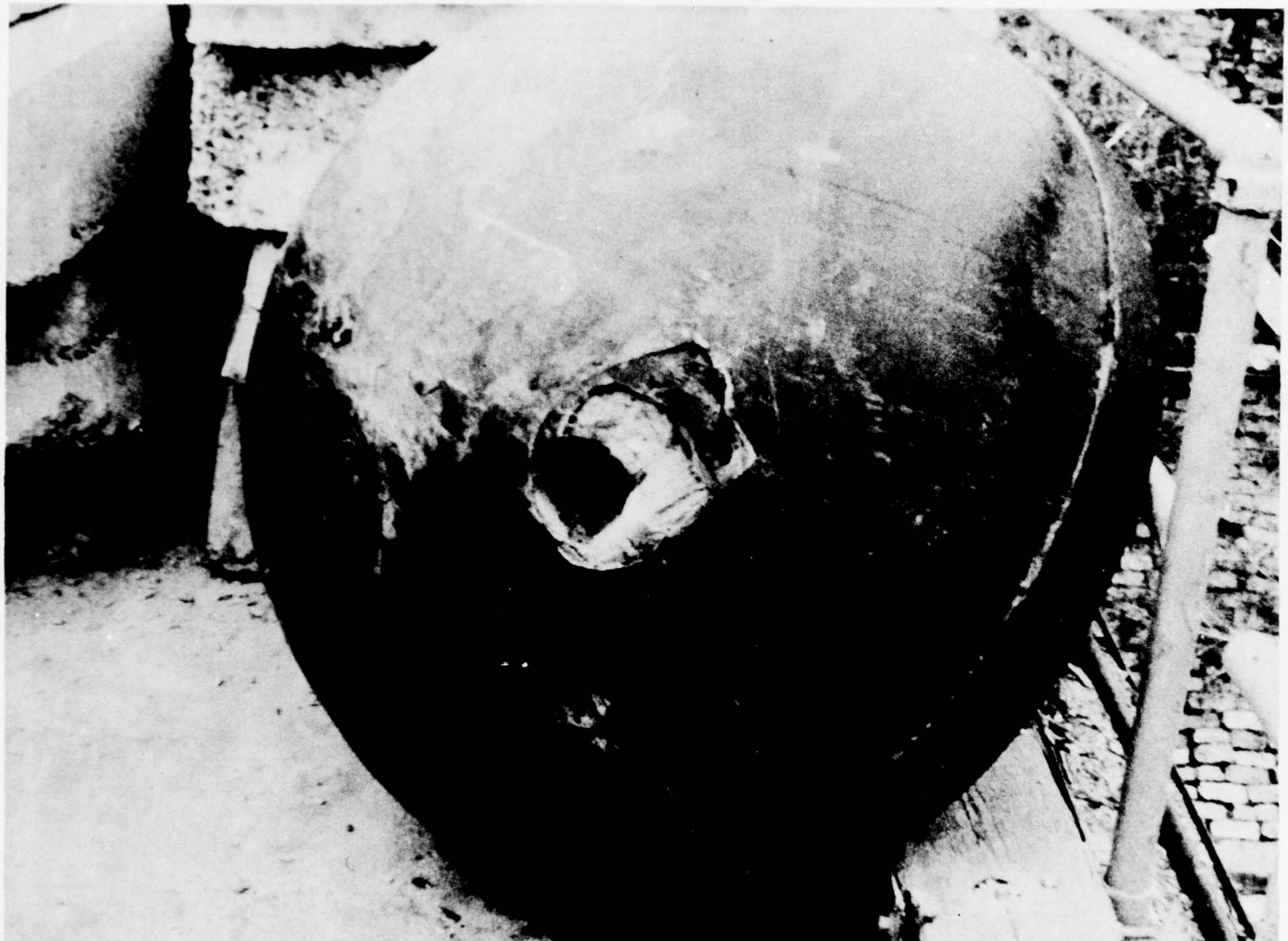


FIGURE 27

Four-foot hemispherical buoy Damage: Side mooring attachment pulled out

NOTE: Though bolt system was not used on test buoys.

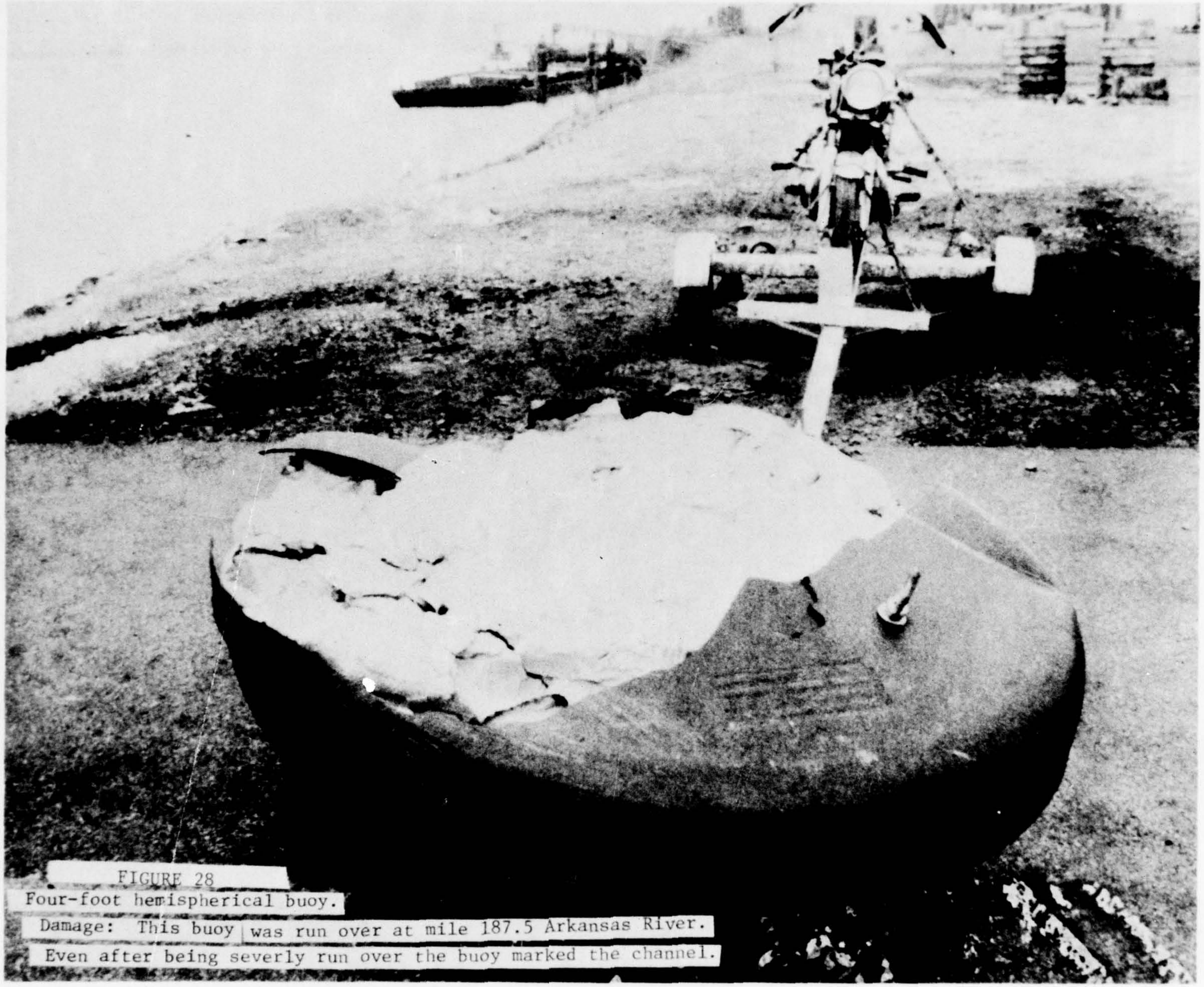


FIGURE 28

Four-foot hemispherical buoy.

Damage: This buoy was run over at mile 187.5 Arkansas River.

Even after being severly run over the buoy marked the channel.

FIGURE 29 - ACCUMULATION OF "MILL GRASS" UPON BUOY MOORING.

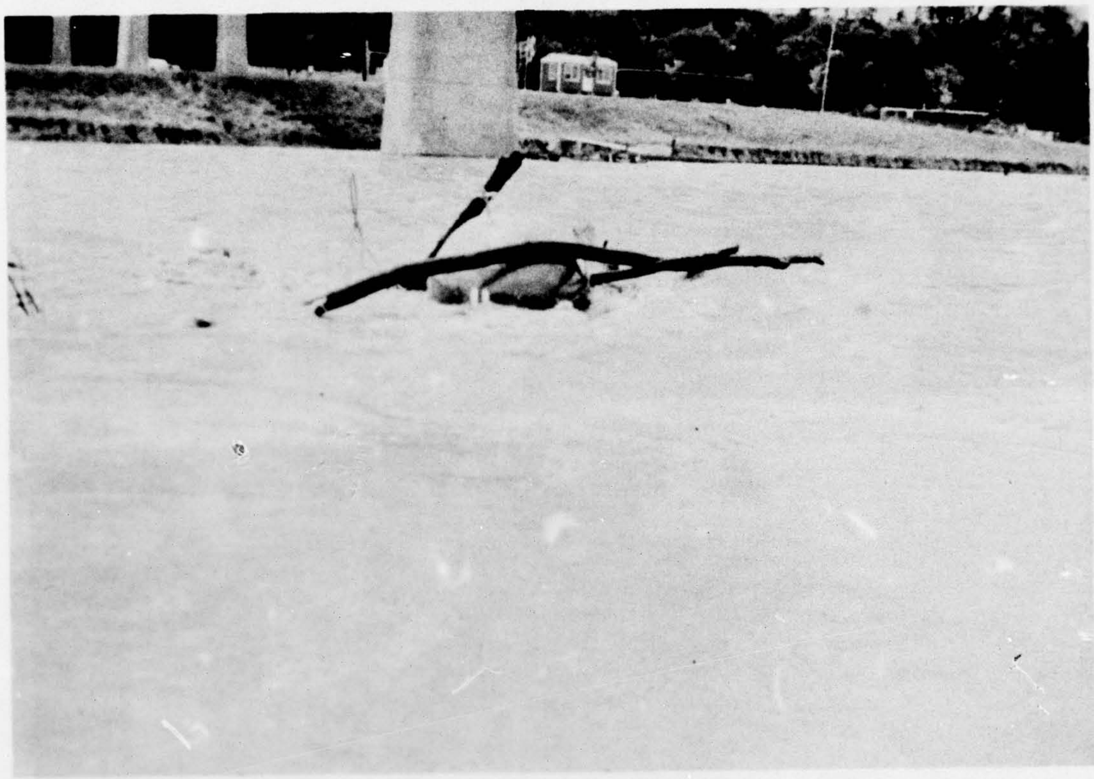


FIGURE 30 - ACCUMULATION OF LARGE DEBRIS AGAINST BUOY HULL

2. The larger types of debris, which consist of waterlogged tree trunks, branches, and stumps, collide with the buoy, and will occasionally catch and become lodged against the buoy hull (Figure 30). The effects of these collisions are hull damage and mooring failure.

Tests show that the effect of debris upon increased mooring tension is significant, and is substantially greater than the sum of the drags considered separately. For example, a 22-foot long log, about 6 inches in diameter, has a drag of about 250 pounds. The drag of a buoy is about 100 pounds. However, if the log catches upon the buoy hull, the combined drag is over 500 pounds.

### 6.3 Debris Accumulation on the Hemispherical Shape

Hemispherical buoys accumulate debris more readily than conventional, cylindrical buoy shapes. This is because the high-riding hemispherical hull forms a sharp "v" between the mooring cable and the bottom of the hull, whereas the cylindrical hull forms an obtuse mooring angle (Figure 31). The acute angle formed by the hemispherical hull easily snares passing debris.

#### 6.3.1 Effect on Hemispherical Performance

Hemispherical hulls, with their large amounts of reserve buoyancy, are not pulled under as debris accumulates (Figure 32). Instead, they remain persistently afloat, and as the mooring load increases, the concrete sinker will drag across the river bottom, and the aid will become off station. As the mooring load increases further, mooring failure will result, either at the mooring eye or by the mooring cable parting.

In comparison, a cylindrical hull does not have enough reserve buoyancy to resist debris accumulation, and it will be dragged under the surface of the water. In doing so, it will often shed the accumulated debris.

#### 6.3.2 Attempts to Solve Accumulation Problem

It was proposed that the acute mooring angle, which caused debris to accumulate, could be widened by lowering the mooring point. This would separate the mooring from the sharp flare of the hull (Figure 33).

To test this theory, twelve model hulls were constructed, of hemispherical, discus, and saucer shapes. The mooring attachment point on all test buoys was lowered by using steel rods of 6-inch, 12-inch and 18-inch lengths. The buoys were deployed in the Mississippi by St. Louis in the outside of a river bend where debris accumulated. The test lasted 30 days, during which heavy debris flows were experienced.

All test buoys, at all mooring locations, readily collected debris, the amount of which was independent of the mooring attachment point. The lowered mooring point clearly was a not a solution to the problem.

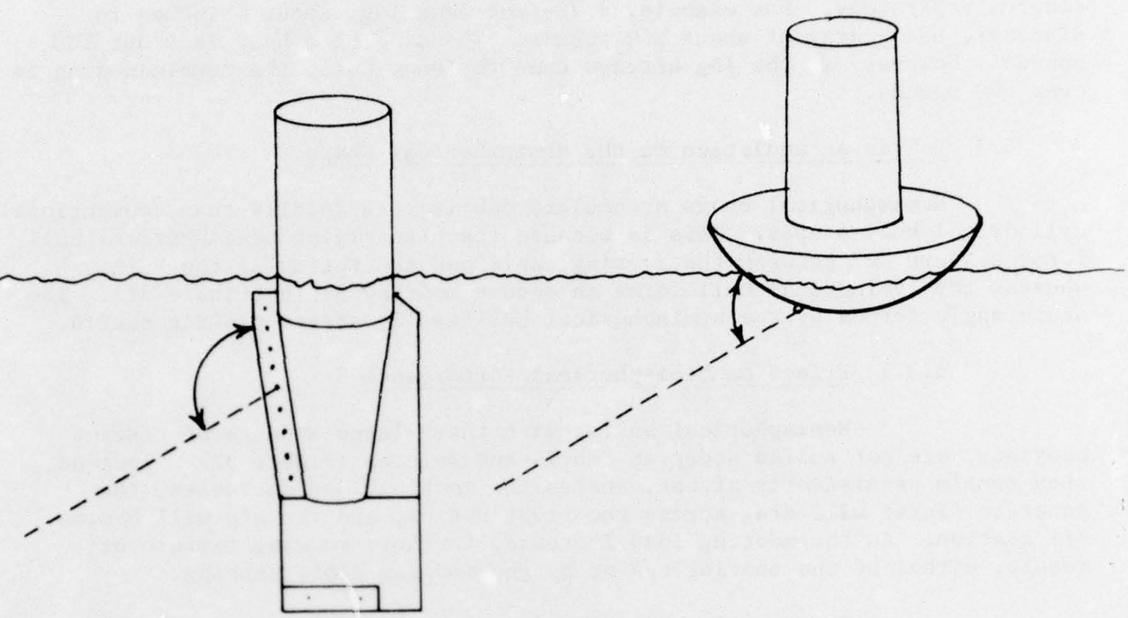


FIGURE 31

COMPARISON OF MOORING ANGLES--CONVENTIONAL HULL VERSUS HEMISPHERICAL HULL. NOTE "ACUTE" ANGLE FORMED WITH HEMISPHERICAL HULL, FORMING TRAP FOR DEBRIS.

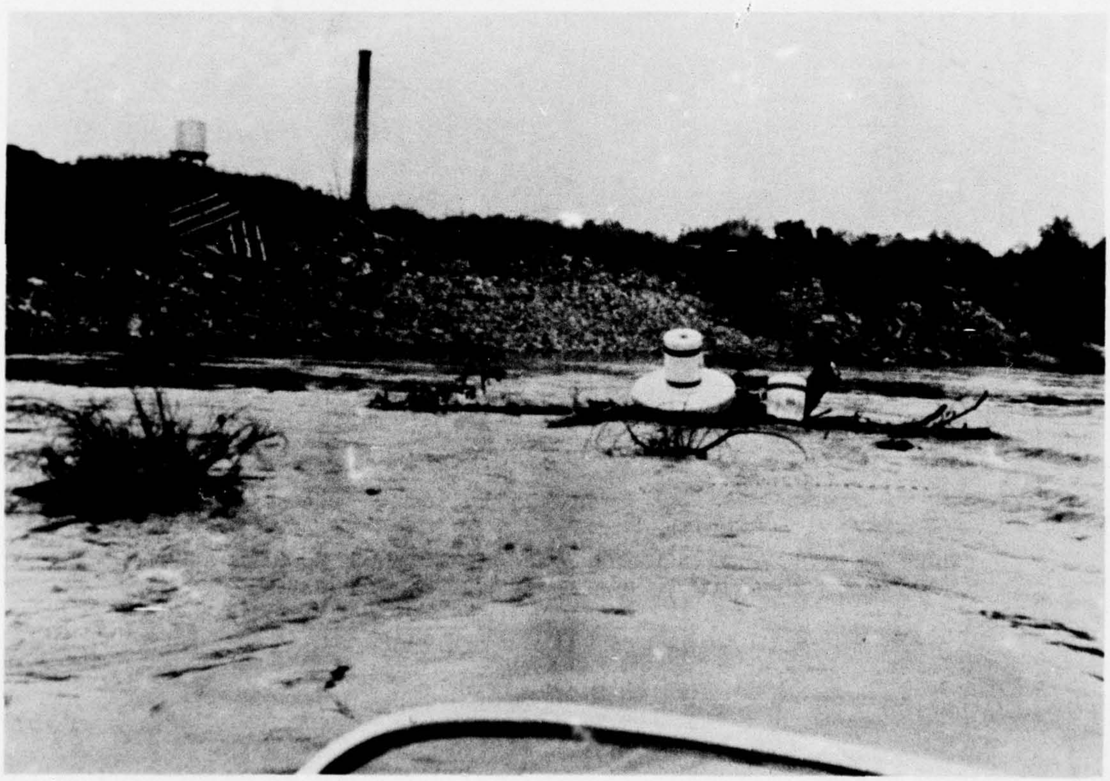


FIGURE 32 - HEAVY DEBRIS ACCUMULATION AGAINST A TEST HEMISPHERICAL BUOY. NOTE HEMISPHERE REMAINS AFLOAT, EVEN HEAVILY LADEN WITH DEBRIS.

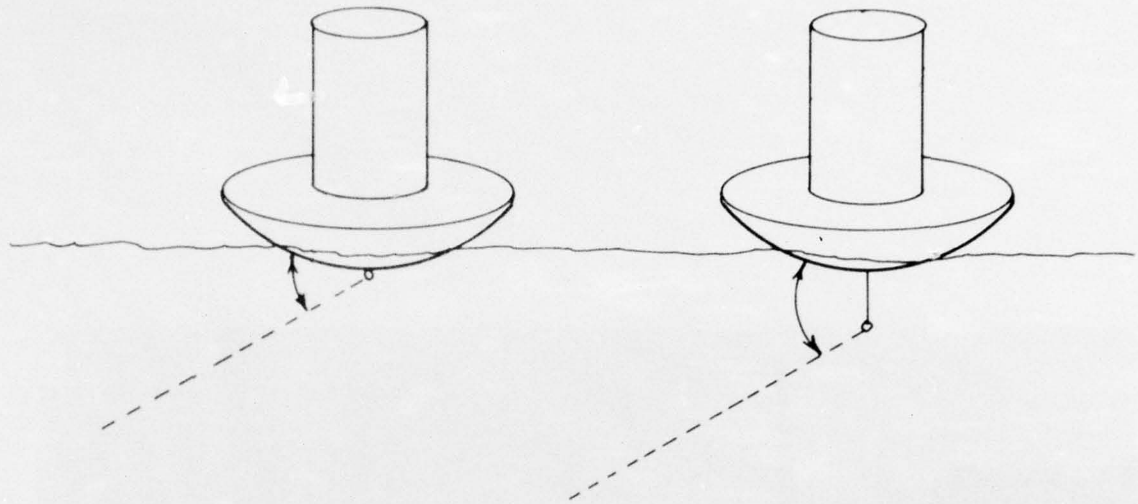


FIGURE 33

LOWERING MOORING ATTACHMENT POINT TO INCREASE MOORING ANGLE.
NOT A SOLUTION TO DEBRIS ACCUMULATION PROBLEM.

6.3.3 A Problem Without "Solution"

As a result of these tests, it was conceded that debris accumulation was an obstinate reality of the river environment. Any buoy, regardless of size, shape, or design, would accumulate debris. The design objective was restated to focus attention upon the hemispherical buoy's particular inability to shed debris once it accumulated.

6.4 Shedding Debris

The cylindrical buoy hull accumulated debris, but it was able to shed debris by either diving or by deflecting it around the buoy; in both cases the path of deflection was away from the mooring. The hemispherical buoy hull accumulated more debris because debris was passed beneath the hull, and thus into the mooring cable. Also, the large diameter cylindrical buoy was able to shed small forks and hooks of passing debris, whereas the small diameter mooring attachment of the hemispherical hull readily collected this small type of debris, adding to the accumulation and further blocking the path of deflection.

6.4.1 Shedding Techniques

Two methods were designed to counter the hemispherical hull's natural tendency to pass debris beneath the hull:

1. The first method was to cause the buoy to spin, thus shedding debris around the buoy hull, away from the mooring. As Figure 34 illustrates, four plastic fins were glued to the base of the hemisphere, and stainless steel swivels were attached to the mooring point to prevent fouling of the mooring cable. With the spin cups attached, the buoy spun as anticipated. The accumulation of small "mill grass" was reduced, but the accumulation of larger debris was unaffected. Larger debris collected at the hull base readily, and in time prevented the buoy from spinning. Spin cups were not the answer.

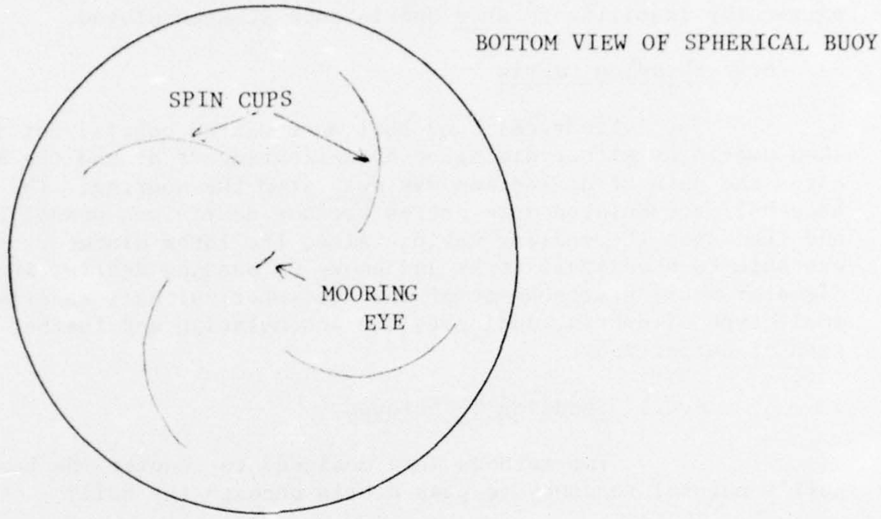
2. Figure 35 illustrates the other debris-shedding device tried, which was a cone attached in line with the mooring. The object of this design was to funnel the flow of water around the hull and away from the mooring. The cones were made of plastic, and buoy performance with these cones was observed for two days. In debris laden water, the hemispherical buoys equipped with the debris shedding cones seemed to resist debris accumulation better than those buoys not cone equipped. While not conclusive, these tests offered a cautiously optimistic solution to the problem.

7.0 OPERATIONAL PROTOTYPES (SPHERICAL SECTION)

7.1 Design Objectives

In late 1975, attention was focused upon the design of an operational prototype. In designing the operational prototype, the objective was to incorporate the favorable riding characteristics of the hemispherical test buoys into a design that also met with the overall operational requirements established at the beginning of the project or as modified by subsequent field testing.

BUOY ROTATIONAL METHOD OF DEBRIS SHEDDING



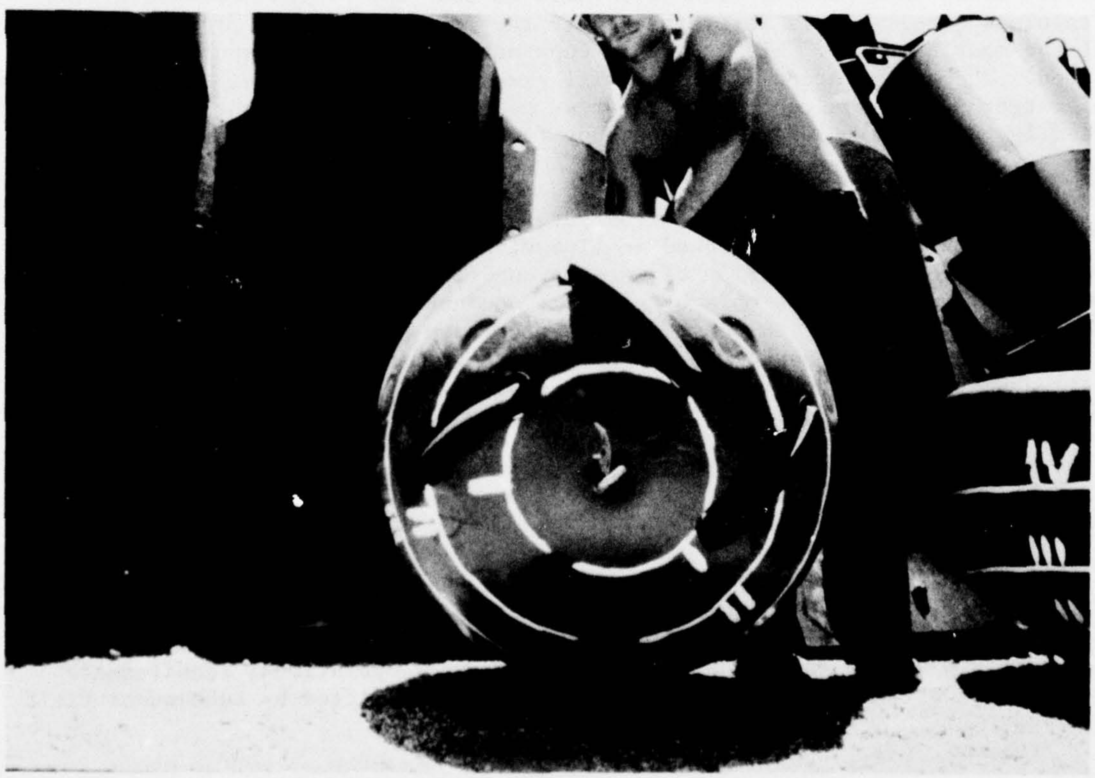



FIGURE 34 - BUOY ROTATIONAL METHOD OF DEBRIS SHEDDING. NOT EFFECTIVE

FAIRING CONE METHOD OF DEBRIS SHEDDING

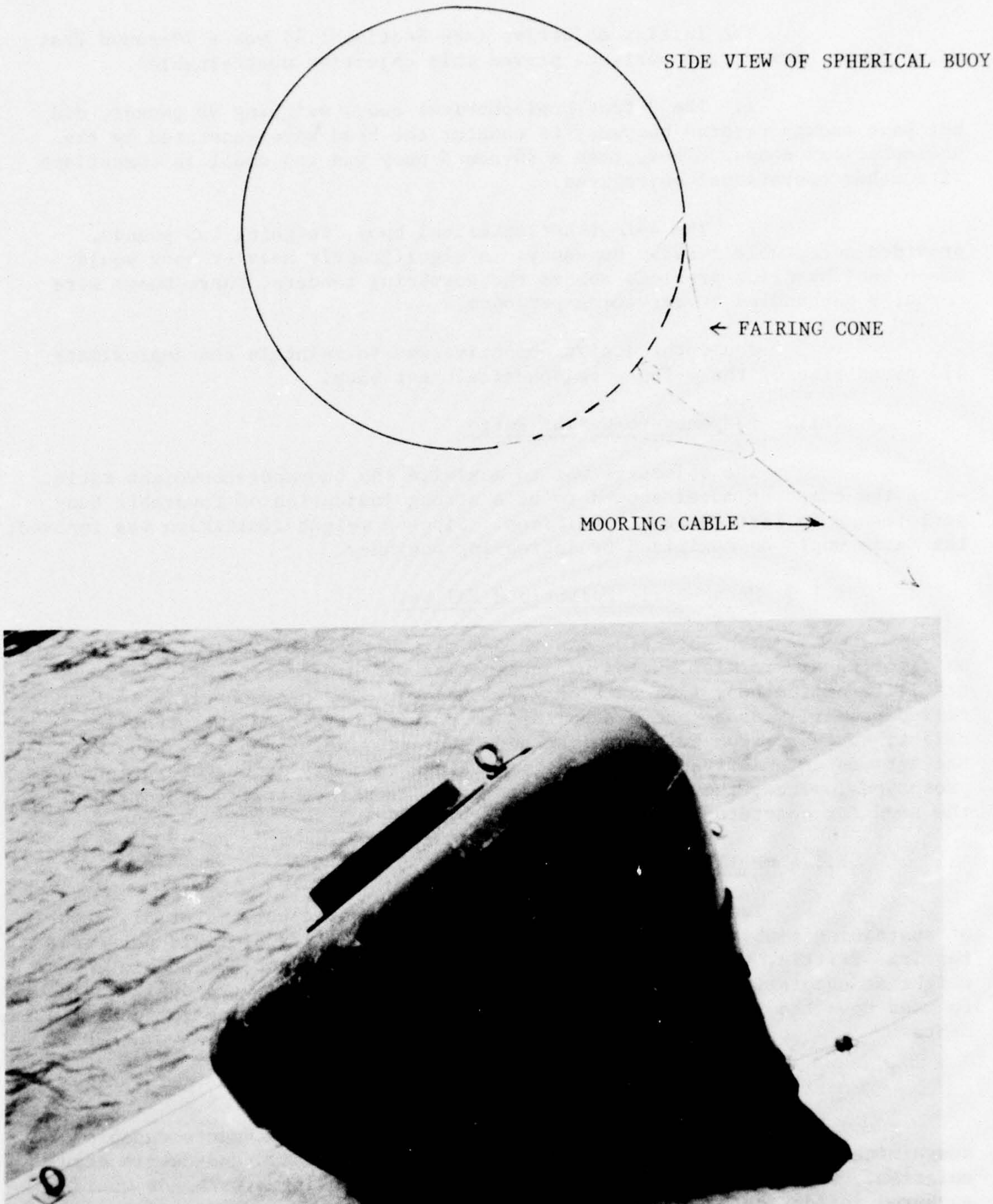



FIGURE 35 - FAIRING CONE METHOD OF DEBRIS SHEDDING. RESULTS WERE PROMISING.

7.1.1 Buoy Weight

The initial objective (see Section 1.4) was a 70-pound Fast Water Buoy. However, experience proved this objective unattainable:

1. The 3-foot hemispherical buoy, weighing 90 pounds, did not have enough reserve buoyancy to counter the head wave generated by the hemispherical shape. Thus, even a 90-pound buoy was too small in comparison with other operational objectives.

2. The 4-foot hemispherical buoy, weighing 135 pounds, provided acceptable reserve buoyancy. A significantly heavier buoy would cause buoy handling problems aboard the servicing tenders, where buoys were normally manhandled by servicing personnel.

Thus, the design objective was to maintain the approximate 135 pound size of the 4-foot hemispherical test buoy.

7.1.2 Buoyancy-to-Weight Ratio

The objective was to maximize the buoyancy-to-weight ratio, which the computer model showed to be a strong indication of favorable buoy performance in fast current conditions. Since a weight limitation was imposed, the ratio would be maximized by increasing buoyancy.

7.1.3 Metacentric Height and Ballast

The objective was to maximize metacentric height, an indicator of righting arm for low angles of inclination which directly influenced the stability of the buoy (see Section 7.2.1 below). The hemispherical test buoys relied primarily upon concrete ballast to provide sufficient metacentric height; however, from both a weight and manufacturing standpoint, concrete ballast was an undesirable means of providing stability in the operational prototypes. Thus, the objective was to maximize metacentric height without the need for concrete ballast.

7.1.4 Hull Materials

The objective was to provide a durable hull material, capable of sustaining towboat collision and within the capability of field personnel to repair. Brittle, temperature sensitive ABS plastic was not acceptable. From a weight standpoint, steel was not acceptable, either. Thus, the design objective focused upon the search for a plastic capable of meeting the operational requirements.

7.1.5 Hull Appendages

The objective was to provide mooring attachments capable of sustaining the mooring tensions caused by towboat collision and debris accumulation. As discussed in Section 5.5 above, the mooring attachment would be anchored inside the buoy hull. In addition, the lifting eye was reinforced by being anchored directly to the mooring attachment imbedded in the buoy hull. In this way, the forces created during the repositioning of the buoy, including breaking the sinker loose from the river bottom, would be transferred directly to the mooring cable.

7.1.6 Daymark

The objective was to provide a daymark with a one-mile range, and .75 mile passive radar range.

7.2 Buoy Stability

The stability of the buoy is expressed in terms of three, somewhat interrelated performance characteristics: buoy trim, the buoy's resistance to capsizing, and the buoy's ability to self-right. The computer model was used to predict the freeboard, mooring tension, and parametric sensitivity of selected spherical segment buoys, and thus arrive at a design solution that met the operational requirements.

7.2.1 Buoy Trim

How the buoy will trim, and how this trim will vary as the current velocity and mooring scope change, depends upon the position of the mooring eye, the magnitude and eccentricity of the longitudinal righting arm, and the radius of the spherical section:

1. Position of the Mooring Eye: if the mooring eye is positioned at the base of the buoy hull, the buoy assumes a severe aft trim in swift currents (as described in Section 5.3.1). Moving the eye away from the bottom of the hull will reduce this aft trim, until an optimal position is reached, at which point an upright (no trim) attitude will result. Moving the eye beyond this optimal position will cause the buoy to assume a forward trim.

The optimal positon of the mooring eye depends upon the velocity of the current and the scope of the mooring line; thus, this position must be based upon the average river conditions and mooring scope expected. If river currents are below this average, the buoy will trim slightly forward. As currents pass through the average design condition, the buoy will assume a no-trim condition and then assume a slight trim aft. Mooring scopes that are less than the average scope will increase the angle of the forward trim.

In the prototype buoy, the position of the mooring eye was based upon scopes greater than 2.5 to 1. A scope below 2.5 to 1 affected the buoy's ability to maintain sufficient freeboard (as discussed in Section 7.2.4).

2. Magnitude and Eccentricity of the Longitudinal Righting Arm: The longitudinal righting arm is a measurement of the buoy's ability to resist forward or aft overturning forces or the moments they generate. The position of buoy ballast directly influences the size of the righting arm.

The weight of the mooring line on a mooring eye placed forward of the bottom of the buoy causes the buoy to trim forward in slow currents. The buoy's righting arm may be skewed aft by placing ballast aft of the buoy axis, thus counteracting the forward trim until the effect of the weight of the mooring line in low currents is minimal.

This concept for an eccentrically aft located righting arm was used on the four-foot prototype (Section 7.3.2), but not on the five-foot prototype, since it did not have any ballast.

3. The Radius of the Spherical Section: In swift currents, the larger the radius of the spherical section, the smaller the attachment point angle (measured from the bottom of the buoy) must be.

7.2.2 Resistance to Capsizing

The buoy's ability to resist capsizing is controlled primarily by the transverse and longitudinal righting arms. Provided that the buoy has sufficient freeboard to prevent the deck from becoming awash, the greater either the transverse or longitudinal right arms are, the more resistant the buoy is to capsizing.

When there are no mooring forces present, the transverse and longitudinal righting arms are equal in a buoy that does not have eccentric ballast. An aft eccentric ballast improves the buoy's resistance to capsizing.

The mooring eye attachment position, as discussed in Section 7.2.1 (subsection 1), also influences the buoy's resistance to capsizing.

7.2.3 Ability to Self-Right

The ability of the buoy to self-right after being capsized by collision, debris, or wind gusts is controlled by the following factors:

1. Transverse and Longitudinal Righting Arms, as discussed in Section 7.2.2.

2. The Daymark. The addition of a daymark atop the buoy hull would change the existing height and weight of the buoy, both of which would have to be countered by other design modifications. Also, the daymark would significently affect buoy hydrodynamics, because, should the buoy submerge, the daymark would act as a rudder and counter the buoy's self-righting moments. This same effect was observed in the compartmented radar reflectors on cylindrical buoys, as discussed in Section 2.4.1.

3. The Attachment Point of the Mooring Eye, as discussed in Section 7.2.1.

4. The Accumulation of Debris, depending upon the size and type of debris.

5. A Flooded Daymark, because of its inherent effect upon the buoy's self-righting arms. When the daymark is prevented from flooding or allowed to drain, the ability of the buoy to right itself is thereby improved.

7.2.4 Computer Predictions

The computer model, simplified for use on a programmable calculator (see Section 4.3 above), was used as a design tool. The model predicted the freeboard and mooring forces on selected spherical section

buoys as functions of (1) buoy size, (2) buoy weight, (3) current velocity, (4) water depth, (5) mooring line length, mooring line size, mooring line weight, and (6) an assumed zero trim angle. In addition, the model determined the parametric sensitivity of the buoy's performance. According to the model, the ability of the buoy to stay above water (maintain sufficient freeboard) was: (1) very sensitive to the mooring scope, (2) quite sensitive to the radius of the spherical section, and (3) somewhat (but not critically) sensitive to buoy weight, water depth, and the size of the mooring line.

#### 7.2.5 Design Solution

On the basis of the computer predictions, the design objectives could be achieved while providing sufficient buoy stability by:

1. Increasing the radius of the spherical section, thereby (1) decreasing the draft of the buoy, (2) reducing the mooring forces, and (3) increasing the metacentric height.

2. Reducing the proportion of the sphere used, thereby keeping overall buoy weight within design objectives.

Thus, in comparison with the hemispherical test buoys, the prototype buoys would appear compressed, broader at the top of the hull and with a more pronounced flare in the hull.

### 7.3 Prototype Design

#### 7.3.1 Hull Materials

A newly designed plastic called high density cross-linked polyethylene was selected. There were two factors which influenced this selection decision.

1. The crosslinked polyethylene was more durable than the ABS plastic. Compared with the known brittleness of the ABS at about 40°F, the polyethylene's brittleness temperature was less than -180°F. Its tensile strength was 2600 pounds per square inch. Actual tests on the polyethylene using sledge hammers showed the plastic to be quite resilient, and not likely to crack or shatter upon impact as the ABS plastic had done.

2. Crosslinked polyethylene was conducive to a manufacturing process called rotational molding. In this process, the powdered plastic is poured into an aluminum mold, which is then rotated on two axes while being heated. Internal steel hardware can be inserted into the mold prior to rotation, and is thus made an integrated part of the completed hull. After heating, the mold is spun cooled, and the completed hull is removed. Throughout this process, the hull is uniformly thick, with no bonds or glue joints. While initial mold costs are high, production in the quantities anticipated brought the unit cost for each buoy within acceptable limits, competitive with existing steel prices.

Due to the added strength of the crosslinked polyethylene, hull thickness was reduced from 1/2-inch (in the bottom of the hemispherical test buoys) to 3/16-inch. As with the hemispherical test buoys, the plastic hull was filled with rigid closed cell polyurethane foam of two pounds per cubic feet density. By increasing the area of the spherical section, it was possible in theory to substitute the weight of foam for concrete, thus eliminating the need for concrete ballast. This was done in the design of the 5-foot buoy.

### 7.3.2 Buoy Size--Two Buoy Concept

As the size of the Fast Water Buoy increased, and as the cost of materials escalated each year of the project, it became obvious that a Fast Water Buoy of sufficient size to meet the operational requirements would be costly. With this realization, there was a shift in the development objective. From an economic standpoint, it was better to mass produce Fast Water Buoys capable of providing adequate performance under average river conditions (six miles per hour currents), and then, supplement these buoys with larger, more costly buoys capable of sustained performance under the worst conditions (eight miles per hour currents, which was the original operational requirement). Thus, overall operational cost of maintaining an aids-to-navigation system on the Western Rivers could be minimized by using a two buoy concept.

Thus, two operational prototypes were designed--one for the worst river conditions, the other for average river conditions:

1. Figure 36 details the design of a five-foot spherical section buoy, designed for the worst river conditions. Compared with the four-foot hemispherical test buoy, the prototype increased the radius of the spherical section from 24 inches to 31 1/2 inches, while reducing the height of the hull from 31 inches to 27 1/2 inches. With this change in design, the total buoyancy-to-weight ratio (see Section 7.1.2 above) was increased from 11.1 to 13.4, and the metacentric height rose from approximately six inches in the four-foot test buoy to approximately ten inches--all without the need for internal concrete ballast. Even so, the buoy weighed 140 pounds, and cost (in limited quantities) $320.

2. Figure 37 details the design of a four-foot spherical section buoy, designed for average river conditions. A four-foot hemispherical design was unacceptable, because with the addition of a daymark of one mile visibility, the buoy would require about 40 pounds of ballast for stability, and would weigh about 155 pounds and cost an estimated $350. By reducing the spherical segment by five inches, keeping a 24-inch radius, it was possible to mount an adequate daymark atop the hull and maintain approximately the same metacentric height as the four-foot hemispherical test buoy. With this modification, the four-foot prototype weighed only 107 pounds and cost about $175, based upon a quantity of 200 buoys.

Figure 38 is a side by side comparison of the two operational prototypes. Figure 39 graphically compares the predicted performance of each. Note that the four-foot prototype was predicted to submerge at currents of about seven miles per hour, whereas the five-foot prototype theoretically would never submerge.

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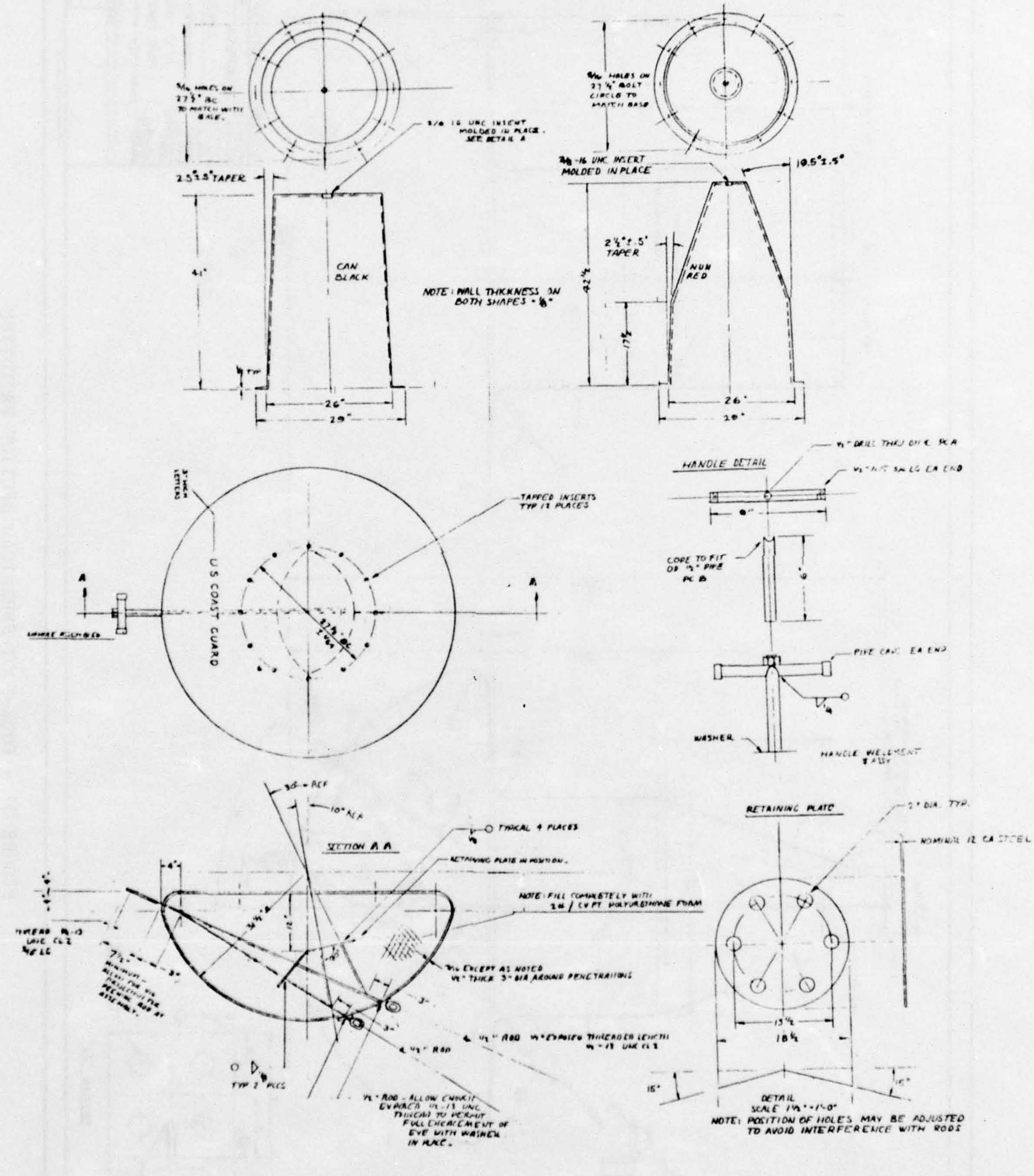


FIGURE 36

FIVE-FOOT PROTOTYPE BUOY

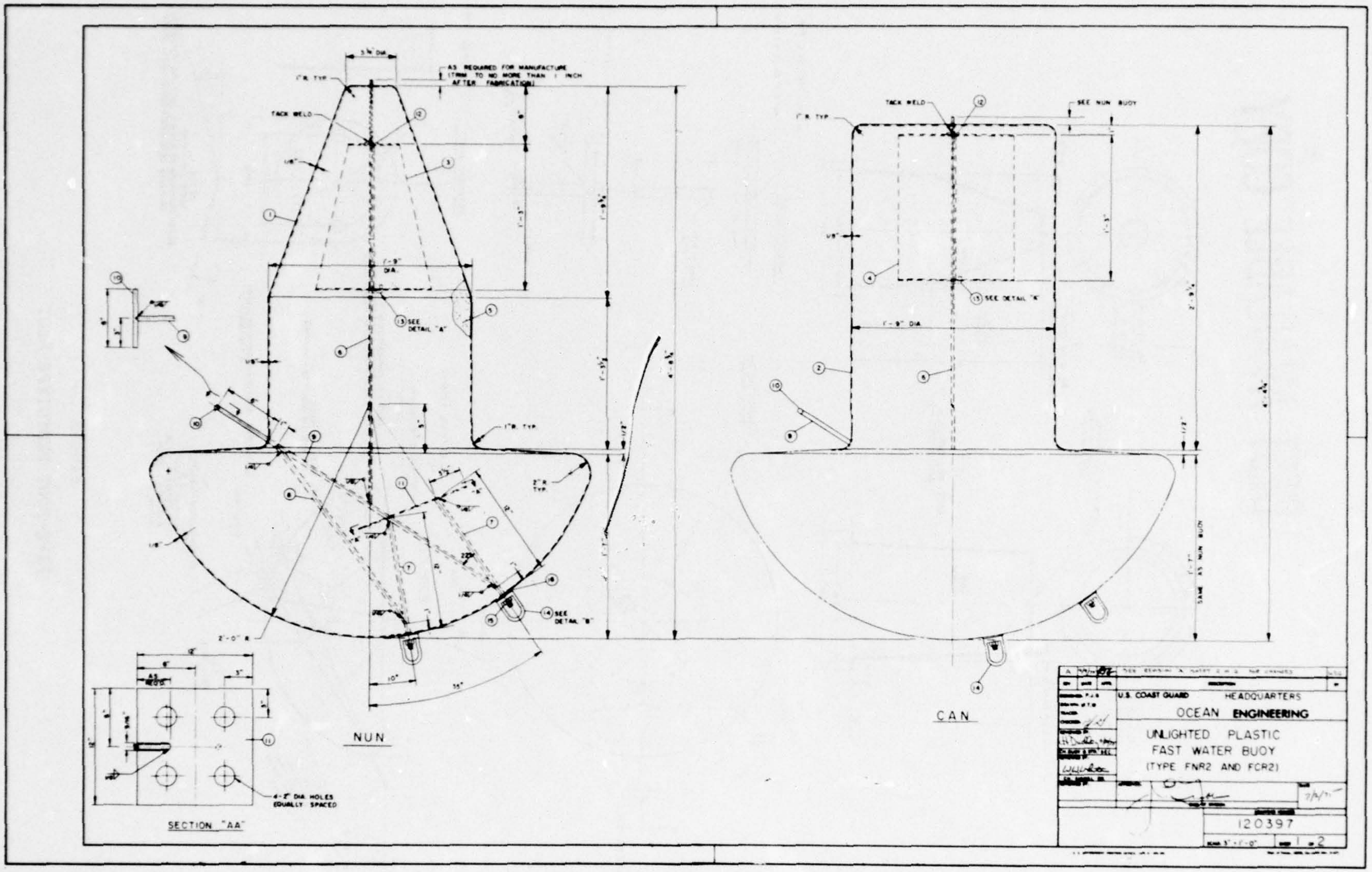



FIGURE 37 - FOUR-FOOT SPHERICAL SECTION PROTOTYPE

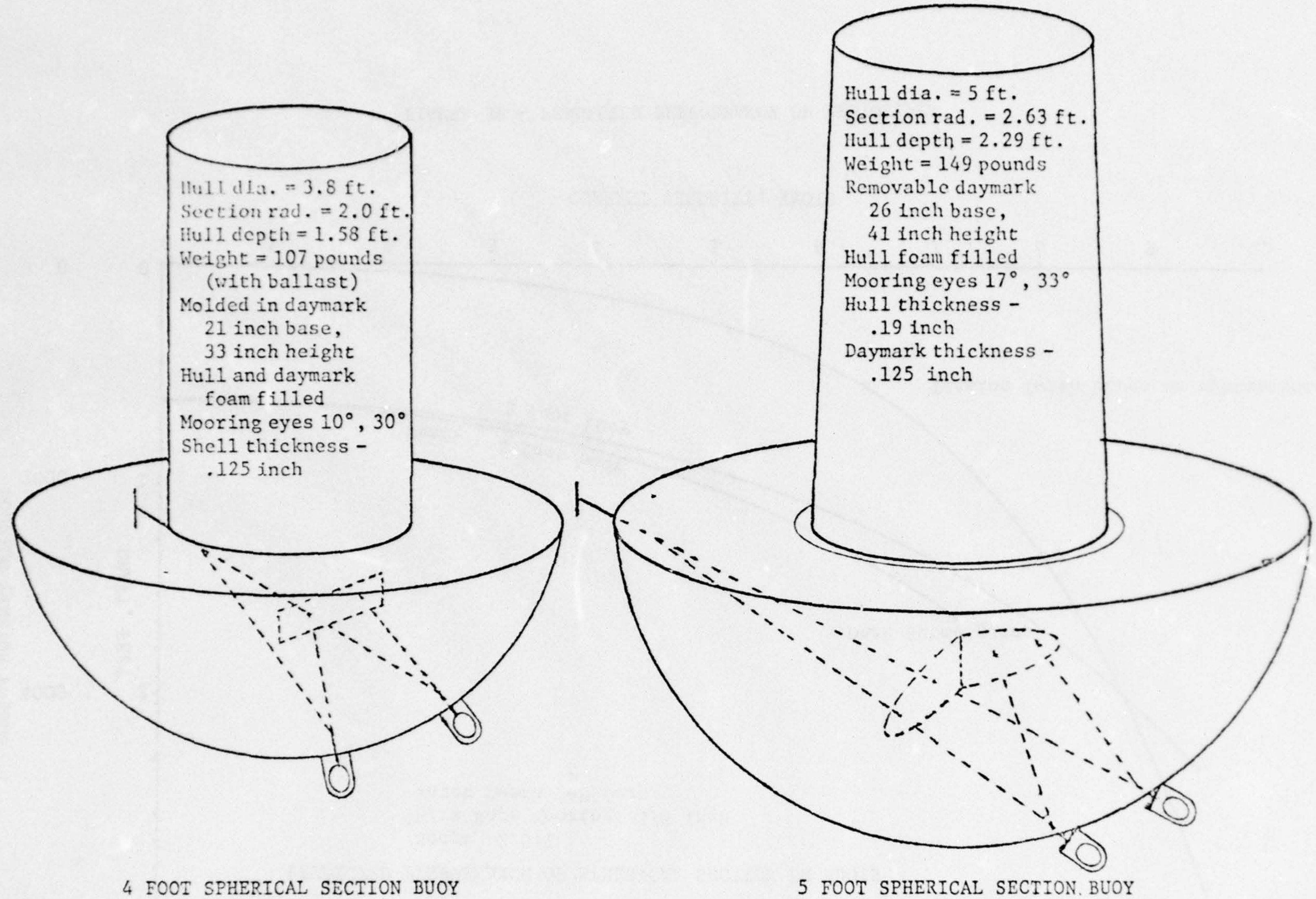



FIGURE 38 - COMPARISON OF OPERATIONAL PROTOTYPES

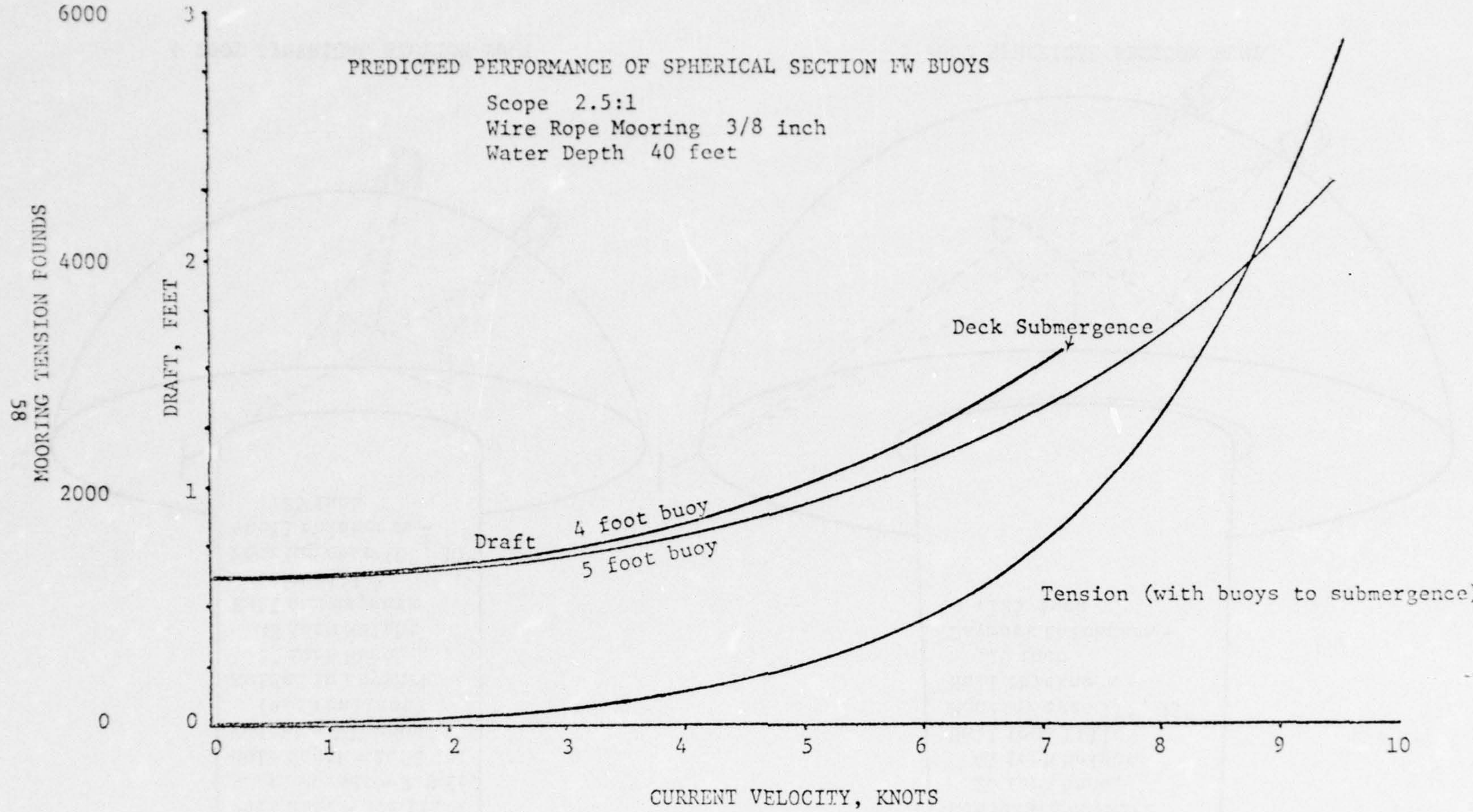



FIGURE 39 - PERDICTED PERFORMANCE OF PROTOTYPES

7.3.3 Daymark Design

The daymark atop the five-foot prototype was approximately four feet tall; atop the four-foot prototype, it was approximately three feet tall. The daymarks chosen provided a theoretical 1.25 and 1.0 mile range respectively. The operative requirement was exceeded to provide a large enough daymark that would be readily apparent and not be detracted from by the size of the hull. However, besides the size of the daymarks, which was dictated by the size of the individual buoys and their individual performance objectives, there was a significant difference in daymark design:

1. The five-foot prototype had a removable daymark that was fastened with screws to the hull. This daymark, also, was hollow, and the radar reflector would be bolted inside. The objective behind this design was to facilitate storage aboard the servicing tender, for the hulls could be easily nested in egg-crate fashion, and the daymarks could be stacked separately.

2. The four-foot prototype had a daymark that was an integrated part of the hull. The radar reflector was permanently attached inside the daymark, and the entire assembly, like the buoy hull itself, was foam filled. The primary objective behind this design was durability. Another advantage of this design was that the daymark would not flood should the buoy capsize, which was a potential problem with the removable daymark. However, the size of the four-foot prototype with its permanently attached daymark posed potential storage difficulties.

Field tests would point to the more suitable concept in design.

Buoy coloration, unlike the hemispherical test buoys, was imbedded in the hull and daymark during manufacturing. This had a definite advantage in reducing field maintenance requirements. The estimated outdoor life of the black (CAN) color was in excess of 10 years; for the red (NUN) color, it was in excess of six years--both within the operational requirements.

7.3.4 Radar Reflector

The difference in daymark design influenced the selection of the radar reflector:

1. Two radar reflector designs were tried in the five-foot prototype, with its removable daymark design (Figure 40). Both designs were lightweight, collapsible and easily stored. One reflector was Coast Guard designed, made of aluminum; the other was commercially available, made of foil-covered foam.

2. The four-foot prototype, with its integrated daymark design, used an aluminum, non-collapsible radar reflector, which was already in operational use in Coast Guard 5th class plastic buoys (Figure 41).

By theoretical calculations, the expected radar range of the three reflectors was approximately one nautical mile, which exceeded the operational requirements.

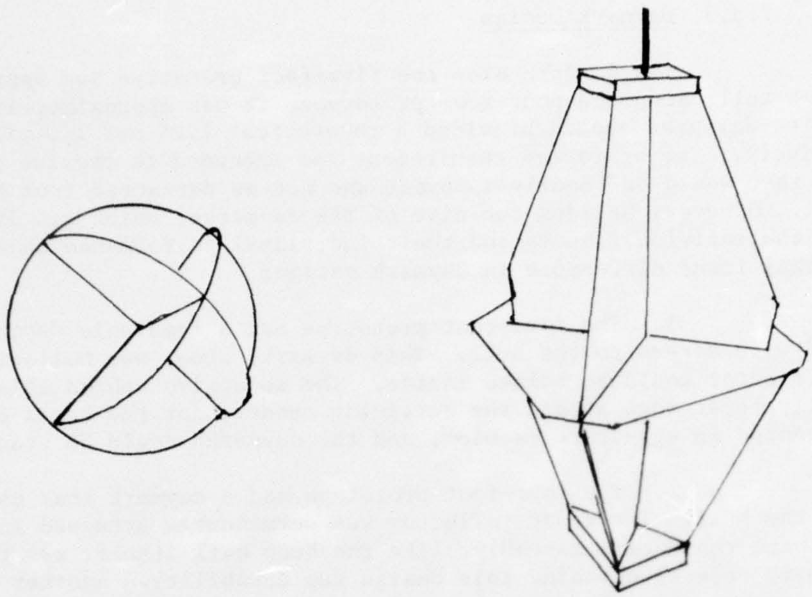


FIGURE 40 - RADAR REFLECTOR DESIGNS IN FIVE-FOOT PROTOTYPE

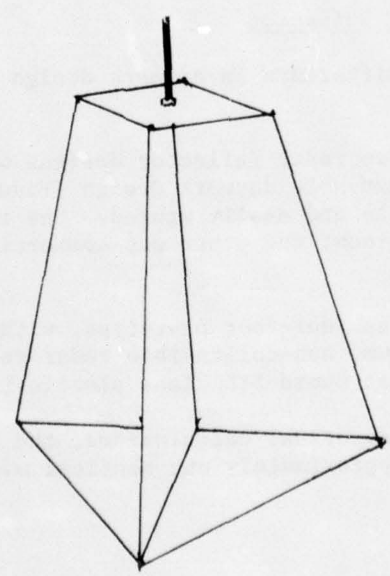


FIGURE 41 - RADAR REFLECTOR USED IN FOUR-FOOT PROTOTYPE

7.3.5 Mooring Appendages

Because of widespread mooring failures in the hemispherical test buoys (see Section 5.5 above), the mooring attachments of the prototype buoys were significantly strengthened. Both four and five-foot models used internal steelwork to reinforce the mooring eye. The through rod was 1/2-inch in diameter and had a minimum tensile strength of 48,000 pounds per square inch. A 12-gage steel anchor plate was used for further strength. The mooring eye was 3/4-inch in diameter, which was capable of supporting 10,000 pounds tension. The only major difference between the internal steelwork was that the five-foot prototype's anchor plate was bent, whereas the four-foot prototype's was flat.

Both buoys had two mooring attachments. The five-foot prototype's were located 17° and 33° from bottom dead center; and four-foot prototype's were located 10° and 35° from bottom dead center. The difference was based upon the predicted hydrodynamics of each buoy.

Instead of using a lifting eye on top of the hull for buoy retrieval, a lifting "T" was used on both prototypes. The objective behind the "T" was to facilitate buoy handling on deck. With the "T" the buoy was more easily grabbed onto than when the small, round mooring eye was used.

7.4 Evaluation of Prototypes

7.4.1 Four-Foot Prototype

The four-foot spherical section prototype was subjected to tank and tow tests, as well as actual deployment in the slack water of Morro Bay and current flows in the Arkansas River and Mississippi River at Memphis. Through these tests, the strengths and weaknesses of the prototype design were evaluated.

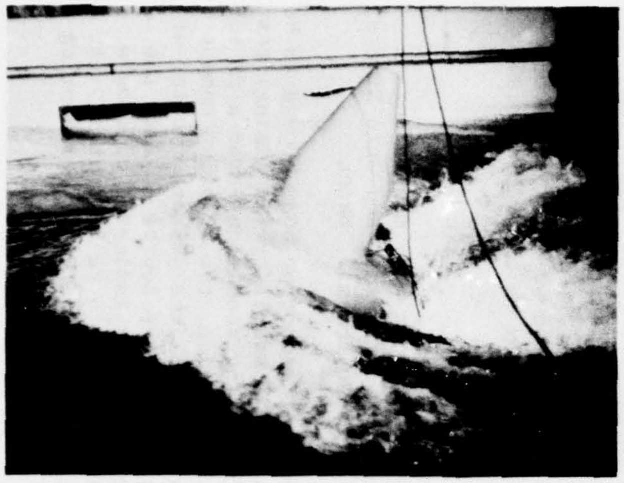
1. Buoy Stability: Early in the evaluation, it became apparent that the buoy, without ballast, was not stable. In calm water, the buoy, moored at the 35° mooring eye, would roll over if disturbed, and would not right itself until the current velocity approached three miles per hour (Figure 42). As the velocity increased, the hull submerged at five miles per hour and capsized at six miles per hour. Again, the buoy would not self right until the current returned to three miles per hour. The instability in slack water could be solved by using the 10° mooring eye, but as currents increased, the buoy would assume an unacceptable aft trim.

A ballast weight of about 30 pounds cured the defect, and the design of the buoy was modified to permit the addition of concrete in the bottom of the hull. This added about $10 to the cost of each buoy.

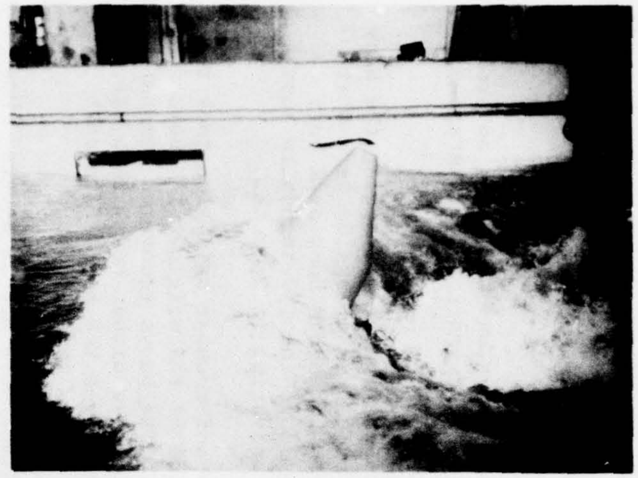
2. Performance in Swift Currents: In tank tests (Figure 43), the prototype performed satisfactorily in currents up to six miles per hour, with ballast added. Above six miles per hour, the buoy became unstable and capsized. In clear water, the use of a debris shedding cone (see Section 6.4.1

FIGURE 42

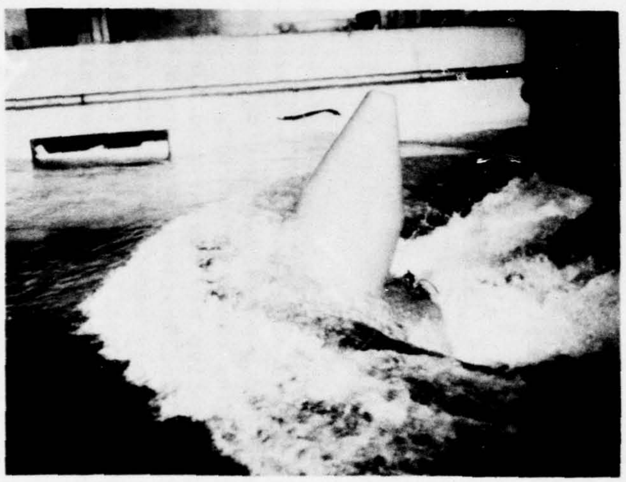
FOUR-FOOT PROTOTYPE IN CALM WATER, ROLLED OVER.
THE CAUSE OF INSTABILITY WAS LACK OF BALLAST.



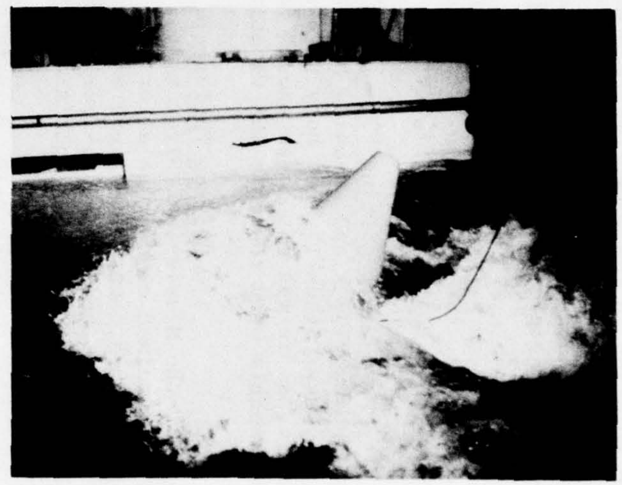
5 Knots - 3:1 Scope - 13 lb.
Ballast no debris shedding cone



6 Knots - 3:1 Scope - 13 lb.
Ballast no debris shedding cone



5 Knots - 3:1 Scope - 13 lb. Ballast with cone



6 Knots - 3:1 Scope - 13 lb. Ballast with cone

FIGURE 43 - TANK TEST OF FOUR-FOOT EOE FAST WATER BUOY

above) did not significantly affect buoy performance. In tests on the Arkansas and Mississippi River, the prototypes displayed performance superior to conventional 4th class buoys, sustaining currents up to six miles per hour, with the hull deck becoming submerged at about 5 1/2 miles per hour (Figure 44).

3. Visibility: The buoys were readily visible at one mile, with either the shape or the color identifiable, depending upon where the sun was in relation to the viewer (Figure 45). Radar range exceeded the .75 mile requirement, often approaching two miles, which surpasses the radar range of the conventional steel buoy. Greater height and visible area of the daymark above the water probably accounts for the superior radar range.

4. Deck Storage: Handling the buoys on deck posed no problems. However, the buoy shape, with its integrated daymark, made storage of the buoy on deck difficult (Figure 46).

5. Lifting "T": The "T" was excellent for dragging the buoy across the buoy deck and grabbing hold of the buoy from alongside in a small boat. However, the "T" made buoy retrieval from the barge buoy deck very difficult, as it was not large enough to accommodate the 1/2-inch wire rope lasso commonly used to snare the floating aid and bring it on deck.

6. Mooring Failures: Debris and towboat collision took their tolls. In the Mississippi River tests, only one of the original 14 buoys deployed remained on station after five weeks. The buoys recovered demonstrated that the common cause of failure was the mooring eye either being torn off, or the entire mooring anchor steelwork being ripped from the hull. The most likely causes were towboat collision and impact from large debris.

The results on the Arkansas River were not as severe. However, the debris accumulation problem (discussed in Section 6.3 above) persisted. On the Arkansas, accumulated debris had to be physically shaken loose from about 150 of the 200 buoys on station. The results of debris accumulation were either dragging the buoy off station or mooring eye failure. However, in currents of five miles per hour, the prototypes displayed superior performance over the conventional 4th class buoy, even while heavily laden with debris.

#### 7.4.2 Five-Foot Prototype

One hundred and eighty 5-foot prototypes were manufactured. They were tested in the Western Rivers (Mississippi, Arkansas, and Ohio Rivers), in the Columbia River, and on the East Coast in Lubec Channel, Maine.

1. Buoy Stability: The five-foot prototype buoy proved to be stable over a wide range of conditions. In a static stability (inclining) test the buoy had a positive righting moment (self-righting condition) over a 0° to 80° inclining range (no mooring). Above 80° inclination, the righting moment became negative and the buoy continued to capsize until the daymark floated at about 100° inclination. (If drain holes were used in the top of daymark the buoy completely overturned.) The metacentric height (an indicator of buoy's stability for small angles of inclination) was measured to be 10 inches. If the suspended mooring weight (or external ballast) attached at either mooring

FIGURE 44

FOUR-FOOT PROTOTYPE (BALLAST ADDED) IN 5-1/2 MPH CURRENT IN MISSISSIPPI RIVER. NOTE: DECK BECOMING AWASH.

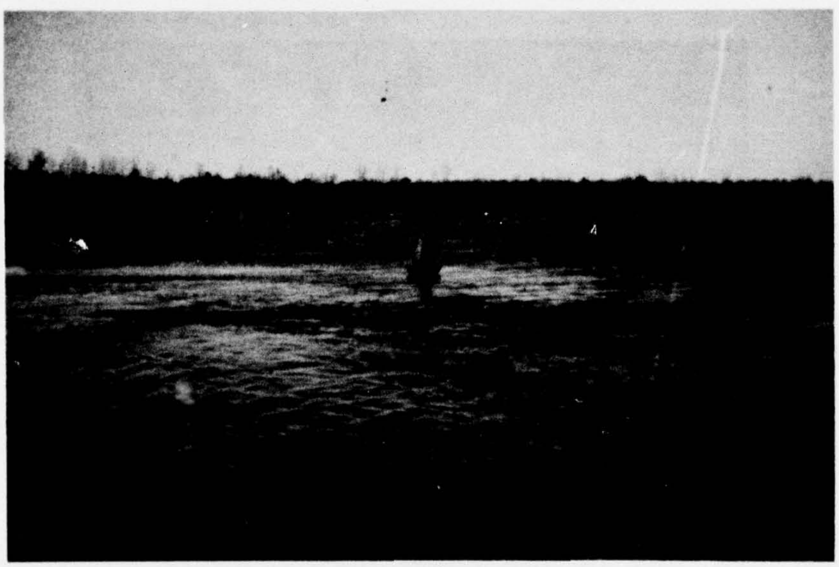


FIGURE 45

VISIBILITY OF FOUR-FOOT NUN PROTOTYPE IN MISSISSIPPI RIVER

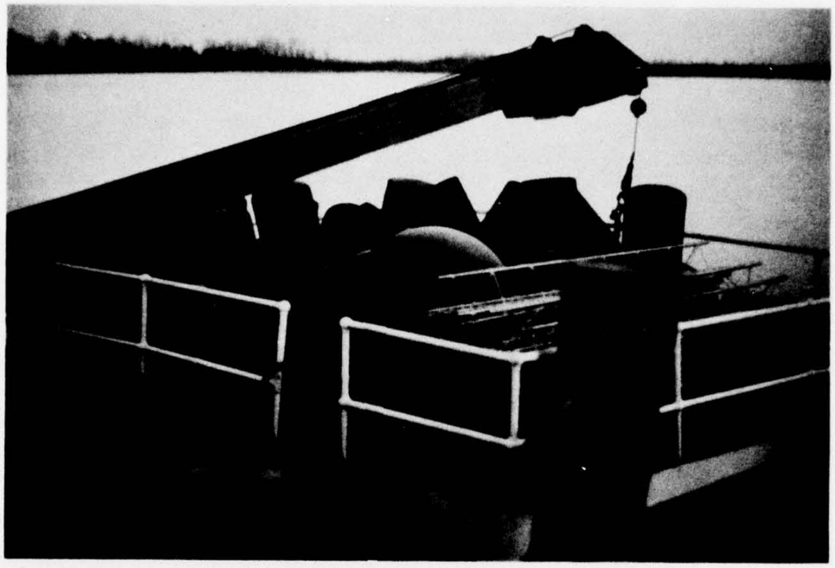


FIGURE 46

STORAGE OF FOUR-FOOT PROTOTYPE ON BOARD TENDER BARGE

FIGURE 47

FOUR FOOT PROTOTYPE (FOREGROUND) AND FIVE FOOT PROTOTYPE IN 5 MPH CURRENT

eye exceeds 35 pounds, a positive righting moment (self righting) was attained over the full range of 0° to 100° inclination.

The buoy is stable over the full range of currents in which it was evaluated (0 to 8 mph) even without the benefit of ballast. Provided that the daymark does not become flooded if the buoy were to be capszied by an outside force such as collision, the buoy will self right in currents above 3 mph without external ballast. If the suspended mooring material (or external ballast) weighs over 35 pounds, self righting is attained over the complete current range (0 to 8 mph).

If the daymark becomes flooded during capsizing, the buoy will self right if drain holes are placed in the top of the daymark around its perimeter (i.e., 4 one-inch diameter holes equally spaced), and if the current velocity exceeds 2.5 mph.

2. Performance in Swift Currents: The five-foot prototype will remain afloat without its decks becoming awash in currents approaching eight miles per hour. In addition, unlike the four-foot prototype, the five-foot model will not become unstable as currents exceed this maximum performance mark, and in theory will never capsize in high current flows. Figure 47 shows the four and five-foot prototypes in side by side performance in five miles per hour currents.

3. Visibility: The visual range of the five-foot prototype exceeds that of the four-foot prototype, and is as much as two miles. Radar range of the two buoys is comparable, exceeding operational requirements.

4. Deck Storage: Calculations show that although a river tender cannot carry as many five-foot prototypes as 6th class buoys, the number of 4th class buoys it can carry is comparable to its five-foot prototype capacity. In addition, the prototype represents a significant decrease in topside weight.

5. Lifting "T": See Section 7.4.1(5).

6. Mooring Failures: A few of the same type of mooring failures reported in Section 7.2.1(6) did occur but not to a very great extent. The latter 144 of these buoys were procured with 0.75 inch through rods in lieu of the 0.5 inch through rods on the 4-foot and the first 36 5-foot prototype buoys. None of the 144 buoys have had their mooring hardware fail.

### 7.5 Improvements of Prototypes

Based upon the field evaluations, the following improvements in prototype design are anticipated:

1. Incorporate a detachable daymark design in both prototypes. This will solve the storage problem encountered. with the four-foot prototype. It will also simplify the manufacturing process. The hollow daymark design of the five-foot prototype should also be maintained; however, drain holes should be added to alleviate flooding problems should the buoy capsize.

2. Add to the lifting "T" a lifting eye that is compatible with existing operative techniques.

3. Increase the diameter of the steel hardware to 3/4 inch.

4. Provide only one mooring eye.

## 8.0 OPERATIONAL FAST WATER BUOYS

The prototype buoys have undergone re-design in order to incorporate design improvements that became apparent in the prototype buoy evaluations. The four-foot diameter prototype buoy became the FNR3 and FCR3 (Fast water; NUN or CAN; Radar reflector) buoys, and the five-foot diameter prototype buoy became the FNR4 and FCR4 buoy; 930 of the FNR3 and FCR3 (465 each) buoys and 504 of the FNR4 and FCR4 (252 each) buoys are being procured at the time of this writing at a per buoy cost of $191 and $195 respectively. The specifications and drawings of these buoys are included in Appendix F.

## 9.0 CONCLUSION

### 9.1 Project Design Review Conference

The objective of the Project Design Review Conference was to evaluate the existing Fast Water Buoy Prototypes in light of operational requirements established at the beginning of the Fast Water Buoy Project, and provide for the termination of the Research and Development's participation in the project.

### 9.2 Evaluation of Prototypes

The following compares the Fast Water Prototypes to the initial operational requirements (Section 1.4):

1. Performance Characteristics: The capability of exhibiting required signal characteristics in currents up to eight miles per hour was modified with the adoption of the two-buoy concept (see Section 7.3.2 above). However, the five-foot prototype meets this requirement for adequate performance in the worst of river conditions. While it is expected that the decks of the five-foot prototype will be awash in eight mile per hour currents, it still maintains required signal characteristics because the daymark remains upright and visible. In addition, a larger buoy poses manufacturing problems, as a five-foot section is the largest size which can be rotationally molded on most existing machines.

As part of the performance characteristics, the ability to support up to 350 pounds of accumulated debris, and shed debris in excess of this amount, was also required. While field data is not conclusive, it is probable that both prototypes are capable of supporting the required amount of debris. As discussed in Section 6.4, debris shedding capabilities have not been perfected and should be the object of further field tests if operational use of these buoys indicates a significant problem exists. The debris shedding cone shows promise.

2. Signal Characteristics: The operational requirement for one mile visibility under average conditions was exceeded.

The requirement for a .75 mile minimum radar range was also met with all types of radar reflectors tested. However, for the purpose of standardization, it was decided to use the radar reflector installed in the four-foot prototype in all Fast Water Buoys, as this model was already in widespread use throughout the Coast Guard.

3. Buoy Durability: The operational requirement for durability in terms of being resistant to impact from towboats and debris was met with the crosslinked polyethylene, within reasonable limits. It is probable that no material, even steel, can withstand the rigors of repeated collisions with towboats. However, the prototype buoys appear to be durable enough. They are foam filled, thus, in theory, are unsinkable.

4. Buoy Maintenance/Storage: The requirement of minimum hull maintenance over a six-year period was met. With the color impregnated within the hull itself, a service period of between six and ten years is anticipated. It is possible to store as many five-foot prototypes on board a river tender as 4th class buoys, with a significant reduction in deck load. Modification of existing buoy pens, now designed to accommodate cylindrical buoys, might be necessary to accommodate large quantities of the spherical section buoys.

The requirement for a buoy weighing 70 pounds was not met. However, it was conceded that, although both the five-foot and four-foot prototype exceed the maximum weight limit originally established, the additional weight is essential if the buoy is to approach the expected performance requirements. Even at their present weight, both prototypes are easily manhandled aboard river tenders.

Buoy maintenance and repair are within the capability of field personnel to perform:

1. Should the daymark inserts on the buoy deck be pulled out by collision, they may be replaced by conventional "molly bolts."

2. Although it is not anticipated that frequent hull painting will be necessary, it can be accomplished by flame treating the hull surface and using epoxy paints.

3. Minor penetrations in the hull can be repaired by readily available "black magic" or comparable commercial products. Flame treating the surface will improve the patch.

4. Although major repairs to a hull have not been attempted, it is probable that they may be done by using a portion of a scrapped buoy, flame treating the patch area and the underside of the patch, and attaching the patch to the area using epoxy or "black magic."

5. Mooring Hardware: The requirement for a mooring eye and lifting eye compatible with present operative techniques was met. With the design improvements discussed in Section 7.5, sufficient strength in the mooring attachments have been achieved.

6. Cost: The original requirement was for a buoy costing no more than \$75. This proved to be an unreasonable requirement, because of the ever-escalating price of materials throughout the project period. The cost of the four-foot prototype was \$175; for a five-foot prototype, the cost was \$320 (for limited quantities). The costs of the buoys being procured for operational use (FNR3, FCR3, FNR4, and FCR4) are \$191 and \$195 for the smaller and larger buoys respectively. These costs are considered acceptable in light of the performance requirements.

## 9.3 Conclusion

Not all of the original operational requirements were met, notably cost and weight. However, the four and five-foot prototype buoys are operationally acceptable, primarily because of their superior performance capabilities and inherent design improvements. The improved operational fast water buoy designs (FNR3, FCR3, FNR4, and FCR4) promise significant operational and economic benefits to the Coast Guard.

### 9.3.1 Operational Benefits

At a range of one mile, the five-foot prototype provides an adequate radar and visual target in currents of eight miles per hour; the four-foot prototype provides the same service in currents of five miles per hour. Thus, both prototypes are superior to existing 4th and 6th class buoys in use. The prototypes' superior visibility has additional benefits: (1) mariners are able, in theory, to sight them sooner and thereby avoid colliding with them. Reducing the frequency of buoy collisions will reduce overall buoy loss on the Western Rivers; (2) with greater visibility, servicing vessels will be better able to locate and retrieve the buoys after mooring failure has occurred, which again works to decrease the presently high buoy loss rate.

### 9.3.2 Economic Benefits

The prototype buoys have inherent design improvements that will reduce the overall cost of maintenance of an aids-to-navigation system on the Western Rivers: (1) with the color impregnated into the hull, there will be no requirement for painting the hull for at least two years, and perhaps up to six years. In addition to the savings in paint purchases, this will reduce field personnel manhours; (2) unlike conventional steel buoys, the plastic buoys do not require welding repairs. "Black magic" or epoxy will suffice for minor patchwork; (3) buoy daymarks, which are prone to more frequent damage, are easily replaced, and cost only about \$40 each. Radar reflectors, too, are easily replaced; (4) the prototype hulls generate relatively low mooring tensions, which might eventually result in a reduction of the mooring size.

## 9.4 Termination of Project

The participation of the U. S. Coast Guard Research and Development Center in the Fast Water Buoy Project is terminated. As the result of an intensive five-year design effort, the Center has provided operational prototype buoys that provide significant improvements in the aids-to-navigation system of the Western Rivers, as well as in other areas where swift currents prevail. With these buoys, the safe and economic use of the Western Rivers is enhanced.

## APPENDIX A
## FAST WATER BUOY DESIGN--EARLY ATTEMPTS

TABLE OF CONTENTS



LIST OF FIGURES

## A.1 INTRODUCTION

This appendix documents with pictures the attempts to improve river buoy performance that were made before the Coast Guard Research and Development Center was assigned the task. The tests were conducted for the most part by Coast Guard personnel assigned to the Aids to Navigation Branch of the Second Coast Guard District, St. Louis, Missouri.

The results of the tests were not documented, except with pictures. The pictures themselves were valuable, however, in that they did assist the Design Study Group to make initial selection/rejection hull design decisions (see Section 3.2 of this report). The pictures also testify to the early concern about the poor performance of conventional cylindrical buoys in swift water.

## A.2 OFF-THE-SHELF BUOYS

Off-the-shelf buoys were considered as a solution to the fast water buoy requirement. Figures 1A through 5A show photographs of some of these buoys tested. From the photographs and what little information is documented, these buoys could not stay above the water in fast currents and/or were not durable to withstand the harsh environment.

## A.3 MODIFYING THE CYLINDRICAL-SHAPED BUOY

Attempts to improve the performance of cylindrical-shaped buoys by modifying the cylindrical buoy design varied greatly in concept and can be divided into five areas (not in chronological order).

The first area was to improve performance by using a shaped ballast which would improve stability as the current increased (Figure 6A). The shape of the ballast would provide negative lift at the bottom of the buoy as the current increased and thereby increase the metacentric height.

The second area was to improve performance by reducing the drag of the below water portions of the buoy by streamlining the shape and/or by adding a rudder (Figures 7A through 14A). Some of these designs also incorporated the addition of a buoyant hull form near the designer's waterline.

The third area was to improve performance by the addition of flotation under (or around) a conventional buoy. An example of this concept is shown in Figures 15A through 17A.

The fourth area was to improve performance by having the buoy rotate by the current flow which would shed debris (Figure 18A).

The fifth area was to improve performance by the addition of hydrodynamic lift fins on the buoy's rudder. Figure 19A illustrates the approach. The fins not only help to lift the buoy in fast current, they also tend to lean the buoy into the current which should aid the hydrodynamic lift of the buoy hull.

The design was borrowed from the Canadians and tested on the Western Rivers. Figure 20A shows a 6th class tall type (Missouri River) buoy (see Section 2.4.1 of this report) with a lifting fin attached. Figure 20A also shows this same buoy providing adequate performance in a five mile per hour current, whereas its normal performance limit (without fins) is about 4 miles per hour. With lifting fins attached, a 6th class buoy performed as well as a normal 4th class buoy.

The fins provided added lift on 4th class buoys as well. Figure 21A compares the performance of a 4th class buoy with and without lifting fins in a current of about three miles per hour. With fins, the visible area of the buoy was reported to be increased by about two feet.

This design modification was not without its problems, however. With lifting fins attached, a buoy thrashed about in the water, as the force of the current flow tends to act unequally against the fins. As the current increased, the thrashing became more severe. The result was excessive wear on the mooring holes of the buoy, which would fail after only a relatively short time on station. To alleviate this problem. the angle of the lifting fins was reduced; however, at the time of this writing, the success of failure of this modification is not known.

"Finned" cylindrical buoys do not provide the consistent swift water performance of hemispherical buoys. Finned buoys, however, might offer limited alternative solution to a fast water problem without major buoy design modifications.

## A.4 NON-CYLINDRICAL HULLS

There were numerous attempts, some as early as 1943, to find a different hull shape to replace the cylindrical hull. In general, there were three buoy types tested: (1) planing discus hulls; (2) boat hulls (both planing and displacement); and (3) spherical/hemispherical hulls.

### A.4.1 Planing Discus Hulls

Figure 22A shows an early discus hull design made of steel. Note that the hull was equipped with a keel and an interchangeable NUN or CAN daymark. This buoy is shown deployed as a CAN in Figure 22Ab.

### A.4.2 Boat Hulls

A diverse variety of boat-type hulls were tested by field personnel, These may be grouped into displacement-type hulls and planing-type hulls. Figures 23A through 28A show photographs of displacement-type hulls whereas 29A is a planing-type hull.

### A.4.3 Spherical/Hemispherical Hulls

As Figure 12 in the main body of this report shows, spherical/hemispherical hulls were being tested by the Corps of Engineers in 1953. Figure 30A shows Coast Guard-designed spherical and hemispherical buoys being tested before the Research and Development Center's participation in the design effort.

Although not a hemispherical hull, the German 5 mile per hour river buoys (Figure 31A) hull is a symmetrical displacement hull (with a non-symmetrical mooring attachment point) that performs in a similar manner as the hemispherical hull.

## A.5 CONCLUSION

Since the early 1940's, Coast Guard personnel have been involved in the search for a fast water buoy. The assignment of the project to the Coast Guard Research and Development Center in the early 1970's represented the first coordinated, fully funded attempt to find a permanent solution to the problem.

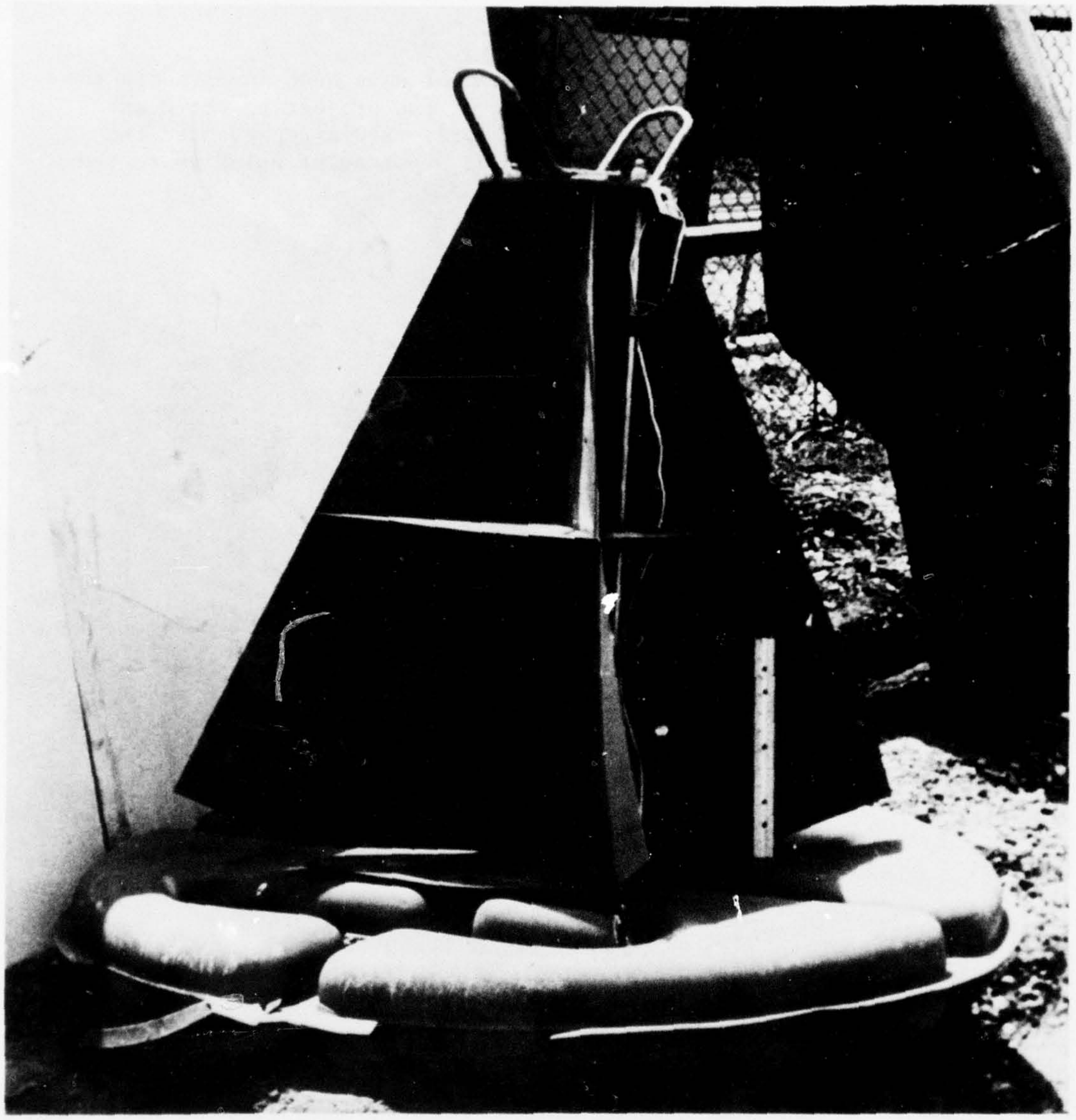


FIGURE 1A - 4NRSL UTILITY BUOY

This buoy was not designed for fast water applications but was tested for fast water performance. No data on performance was available, except that the buoy was rejected because of inadequate resistance to damage.

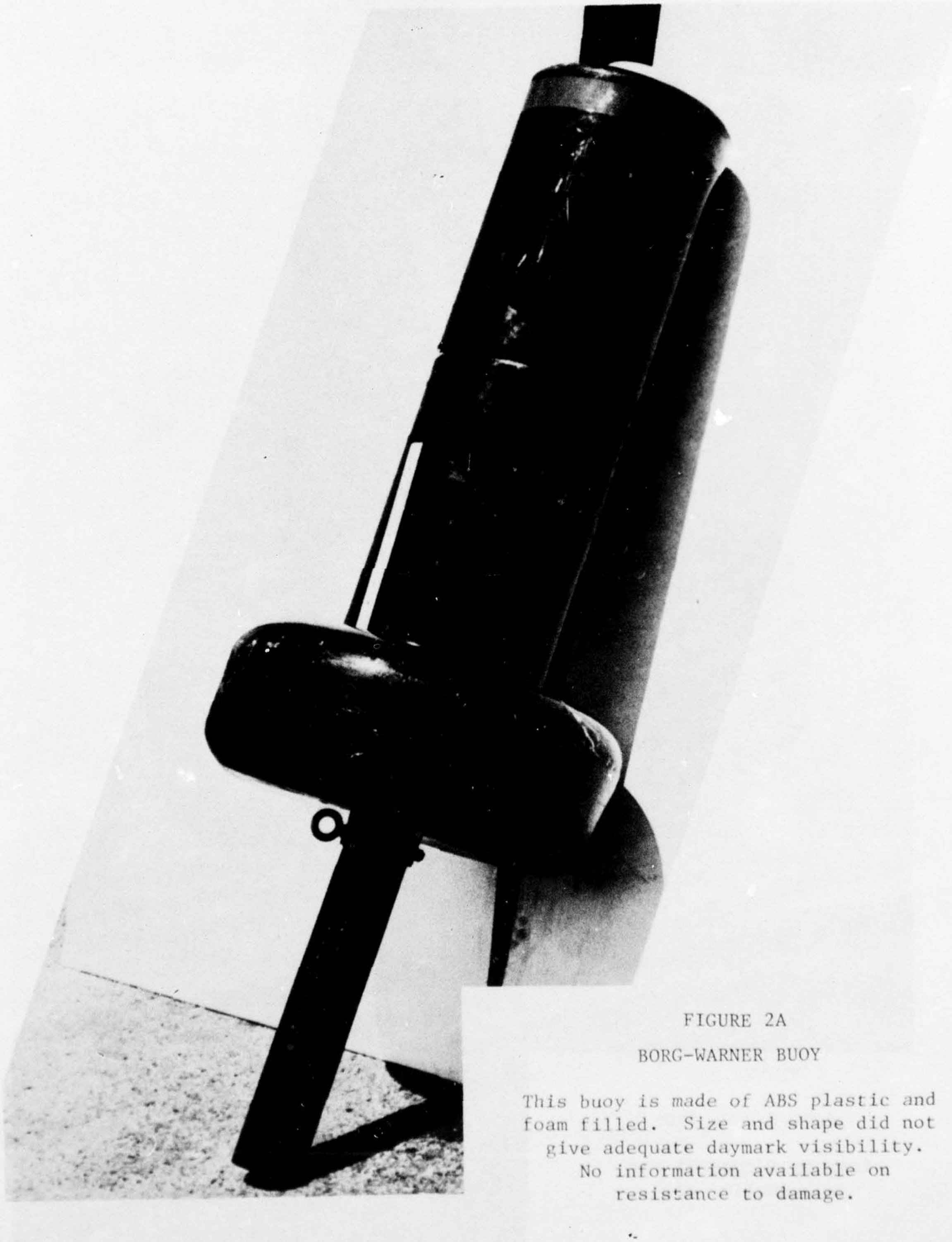


FIGURE 2A

BORG-WARNER BUOY

This buoy is made of ABS plastic and foam filled. Size and shape did not give adequate daymark visibility. No information available on resistance to damage.

FIGURE 3A

BORG-WARNER BUOY

Same as Figure 2A but in a smaller size.

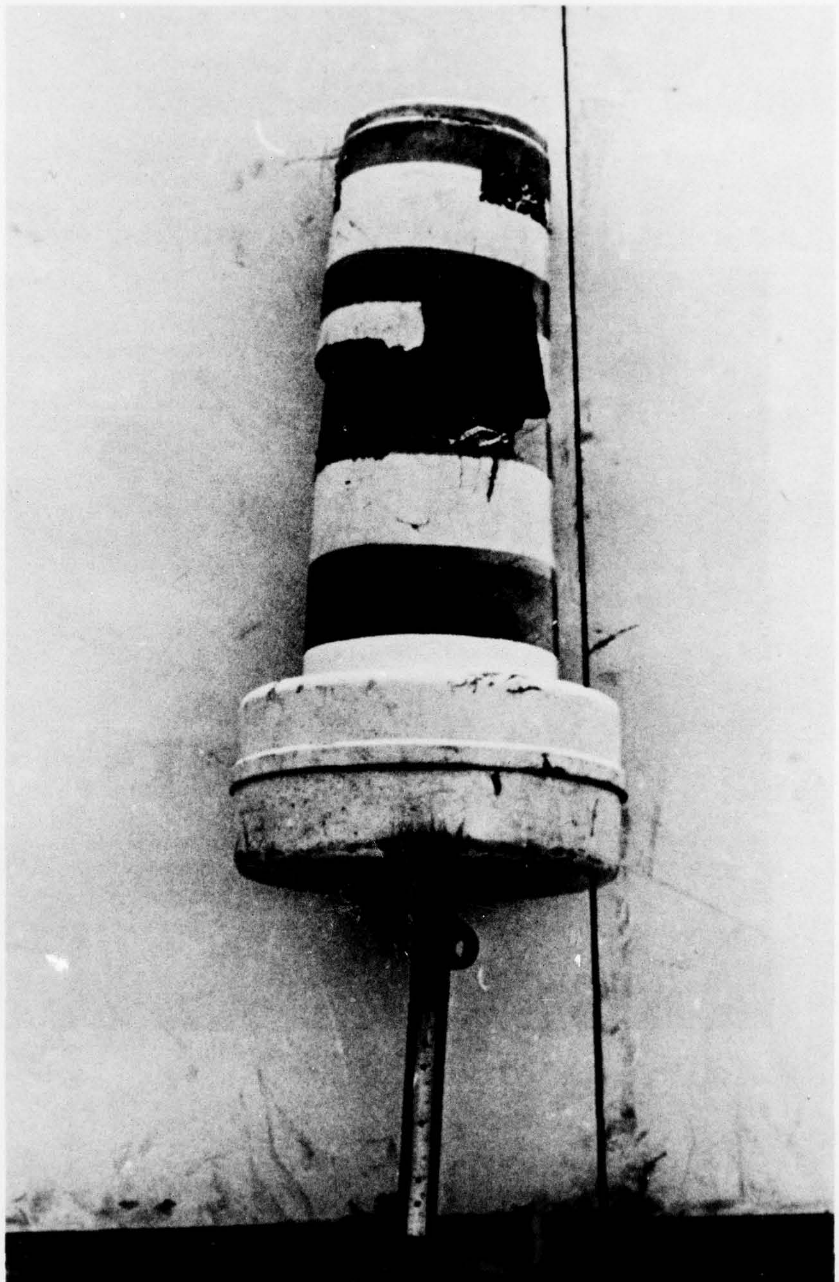


FIGURE 4A - AUTOMATIC POWER BUOY (MODEL BA-323)

No performance information available.

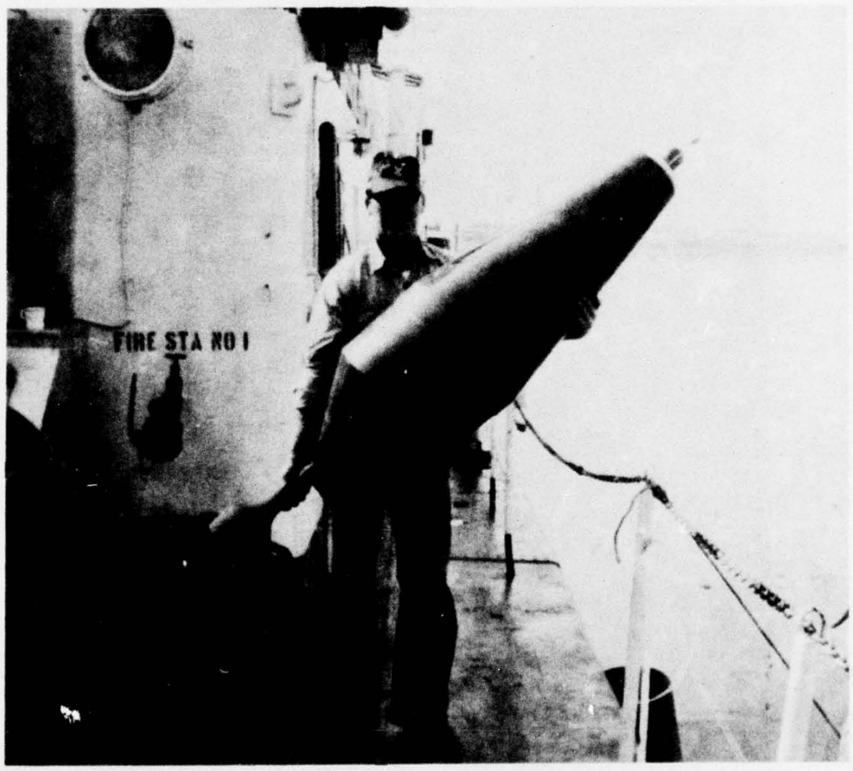



FIGURE 5A

TIDELAND P-4L WINK LITE BUOY

This buoy is a standard Tideland Design.
No performance information available.

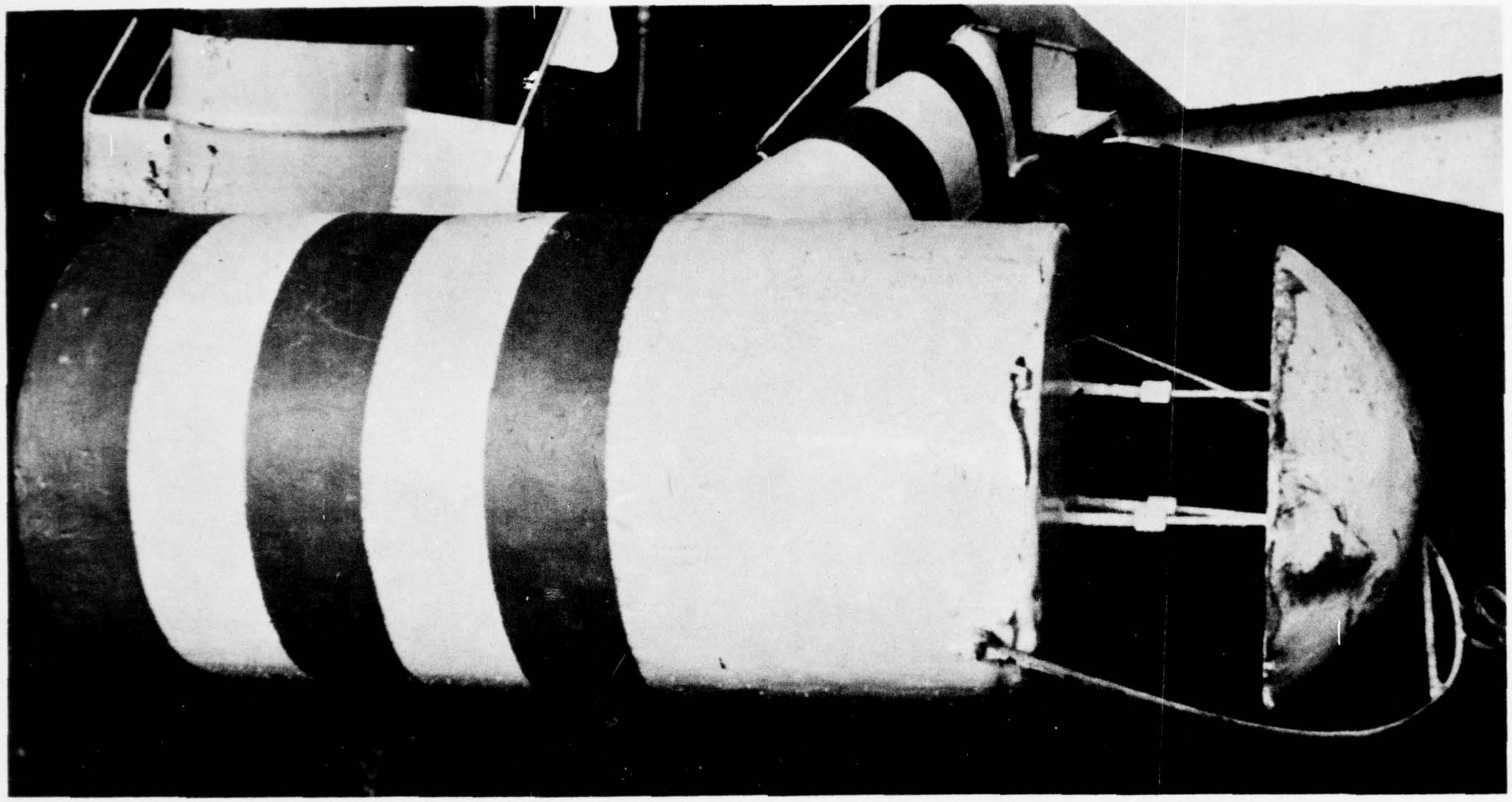


FIGURE 6A - 5CRX - 5NRX PLASTIC BUOY

Reports indicate that the buoy performed well in up to 4 MPH currents. No information was available for higher currents. Buoy was deemed unsatisfactory because of inadequate strength of counterweight support bars and low resistance to collision damage.

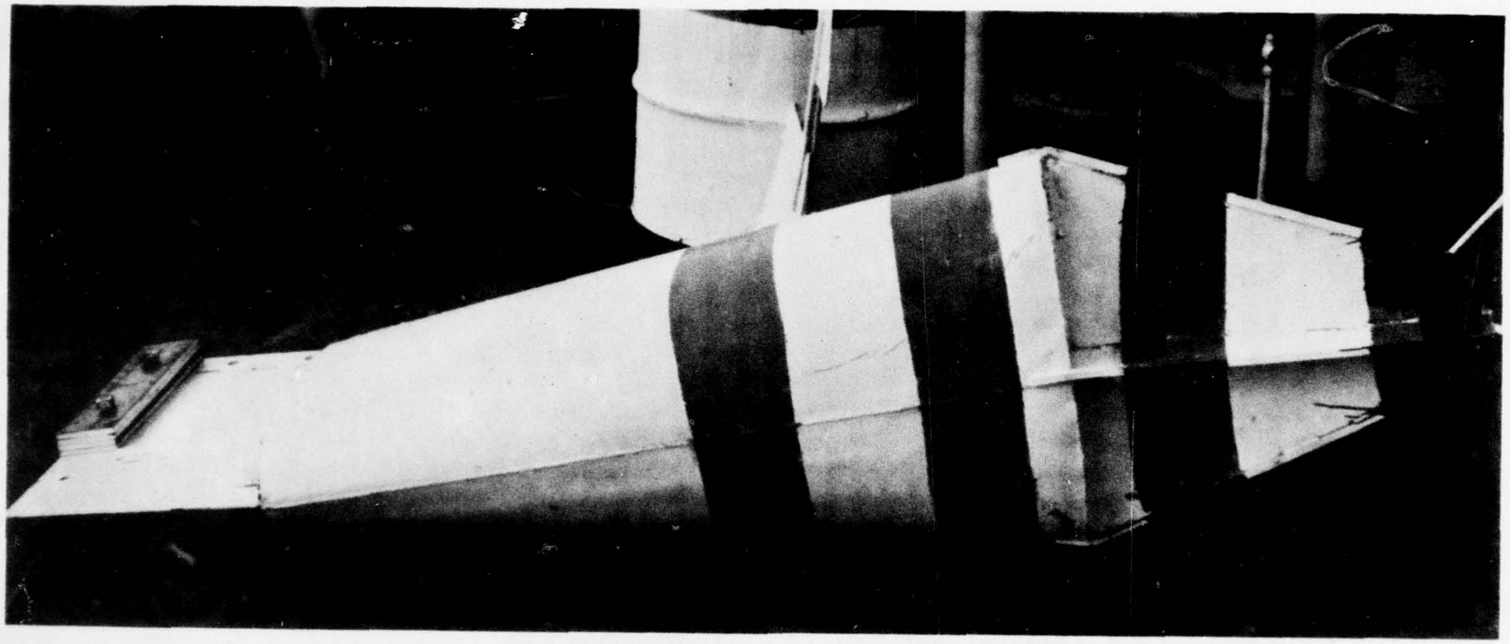


FIGURE 7A - 1963 EXPERIMENTAL BUOY

No information available.

FIGURE 8A - SECOND DISTRICT DESIGN

This design is a modification of a 6N buoy. No performance information available.

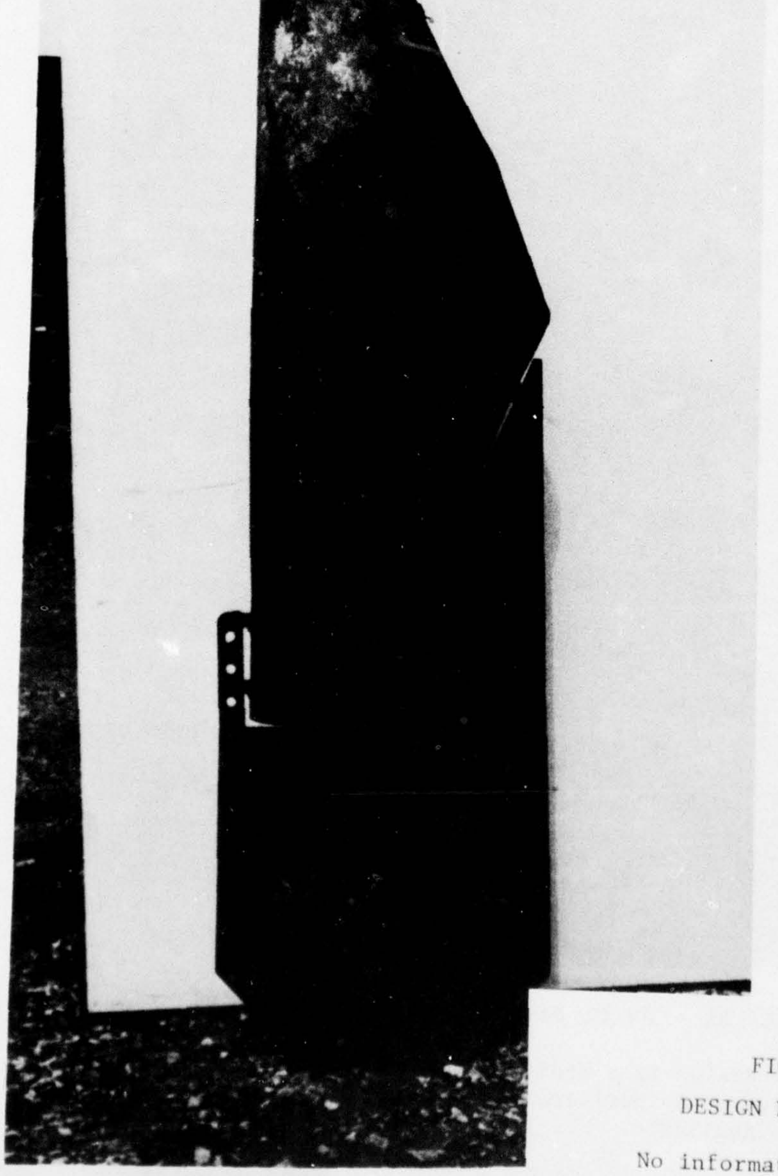


FIGURE 9A

DESIGN NAME UNKNOWN

No information available.

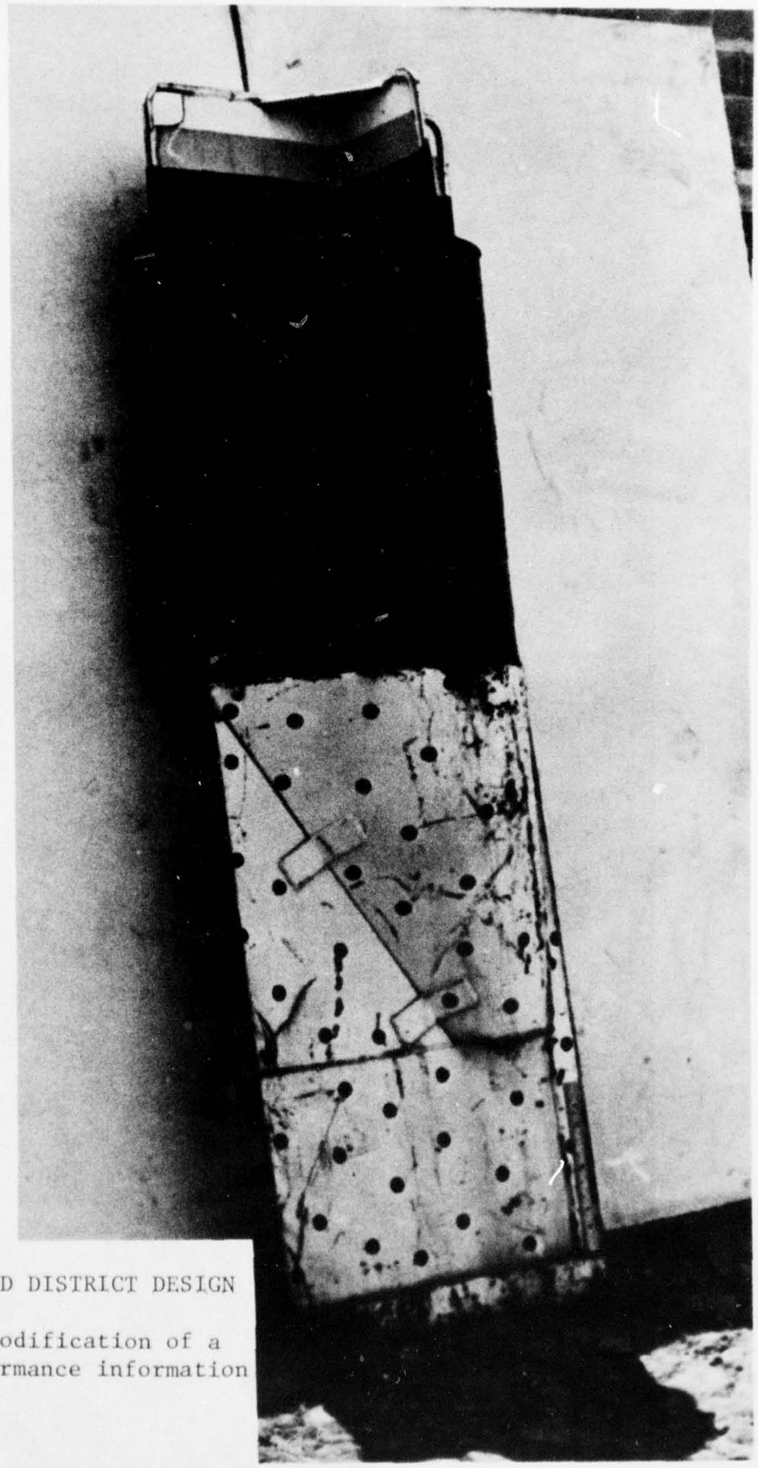


FIGURE 10A - SECOND DISTRICT DESIGN

This design is a modification of a 6C buoy. No performance information available.

FIGURE 11A

6NRF DESIGN

No information available.

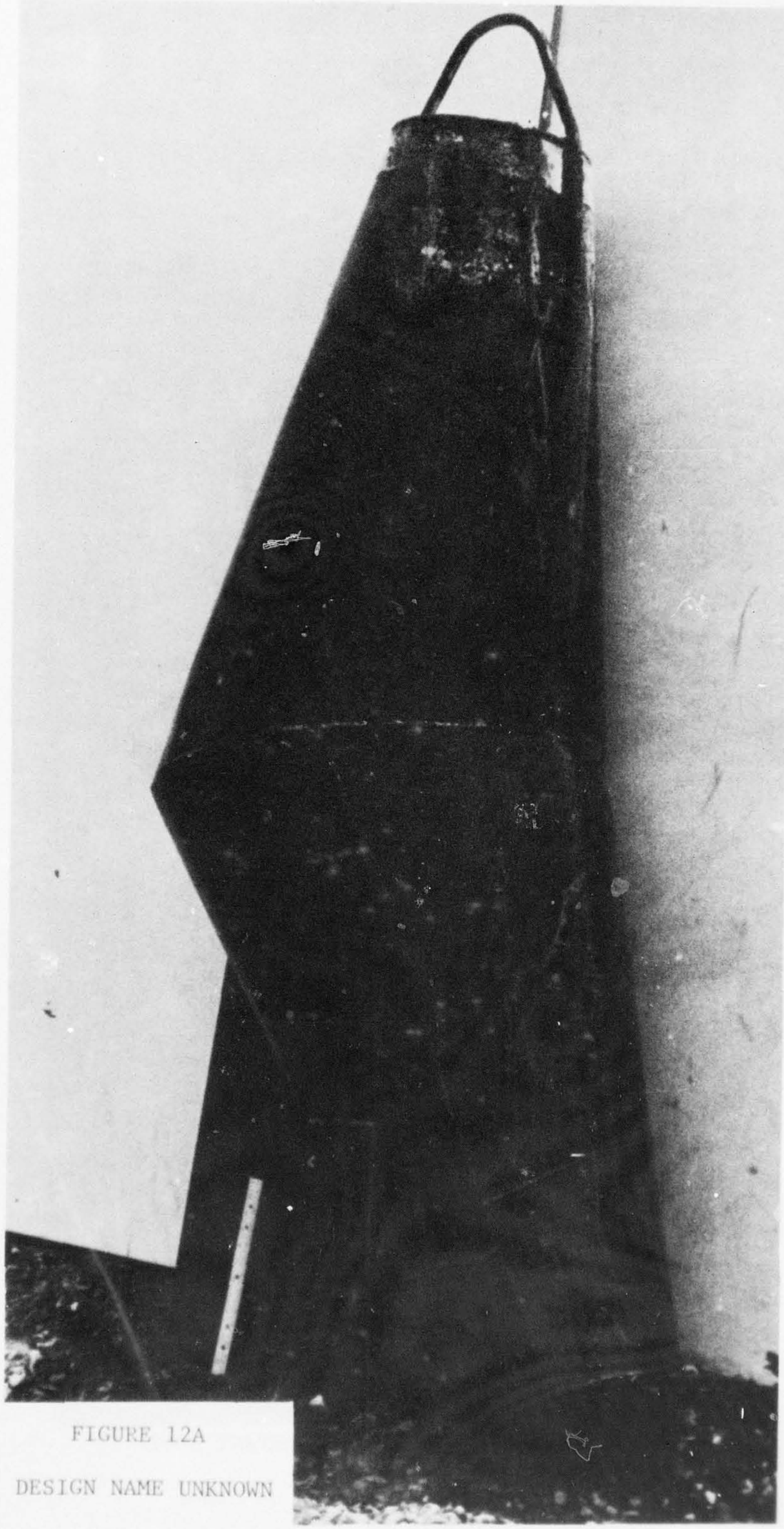


FIGURE 12A

DESIGN NAME UNKNOWN

AD-A039 493 COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CONN F/G 13/10
LIGHTWEIGHT LOW DRAG FAST WATER BUOYS. (U)
DEC 76 W E COLBURN, D D RYAN
UNCLASSIFIED CGR/DC-1/77 USCG-D-5-77 NL

2 OF 2
AD
A039493

END
DATE
FILMED
6-77

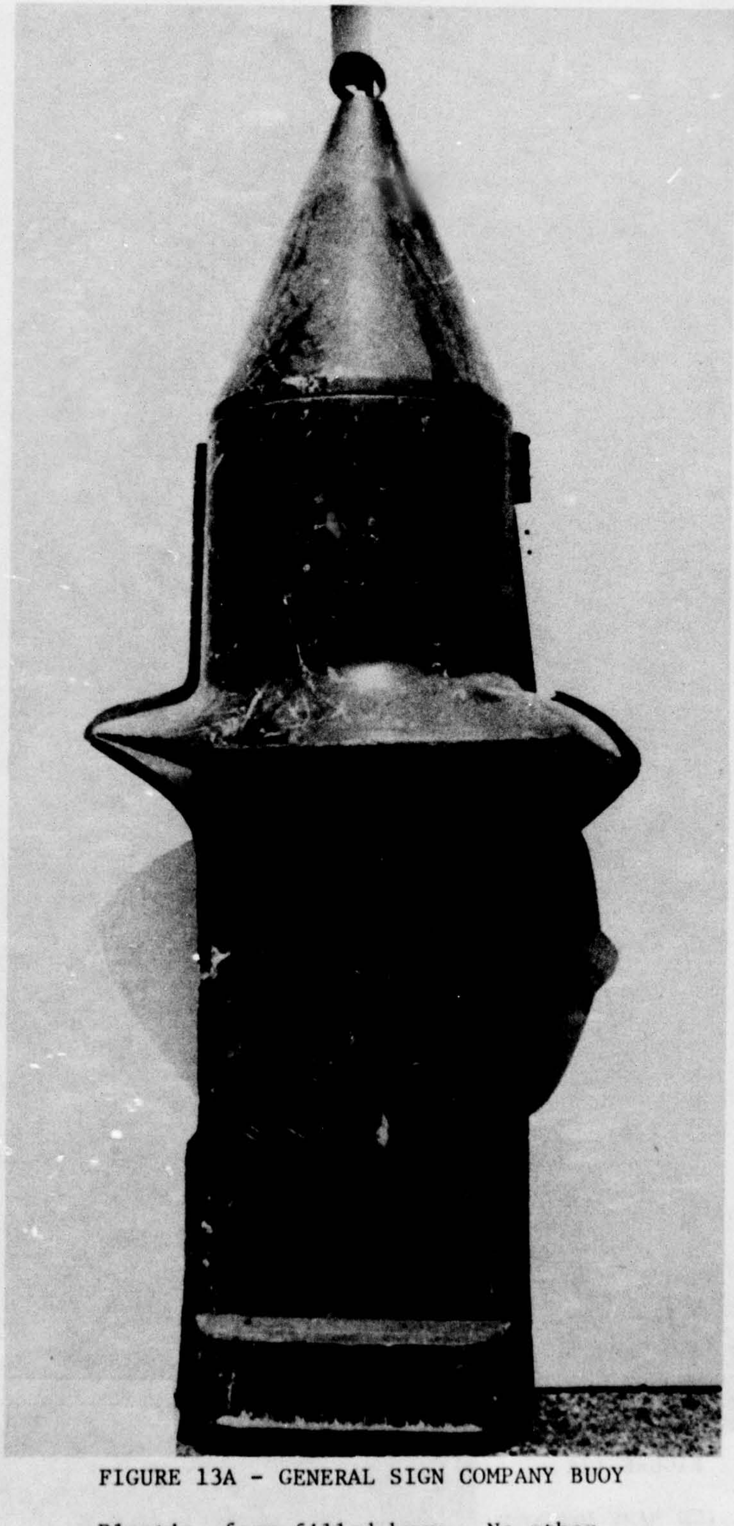


FIGURE 13A - GENERAL SIGN COMPANY BUOY

Plastic, foam-filled buoy. No other information available.

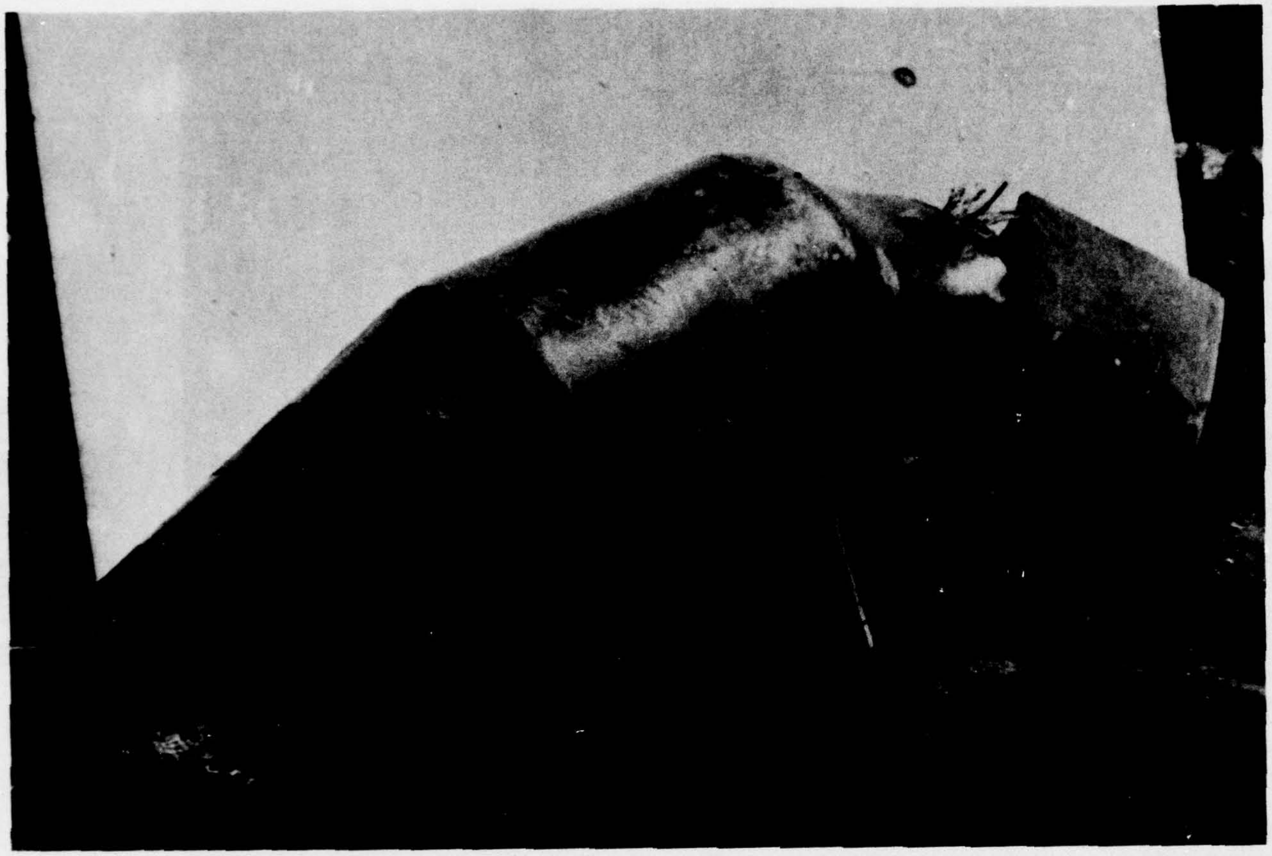


FIGURE 14A - 5NRP BUOY

Picture shows collision damage for this buoy. Eleven of twelve buoys sent to Second District were damaged or lost within 30 days after deployment.

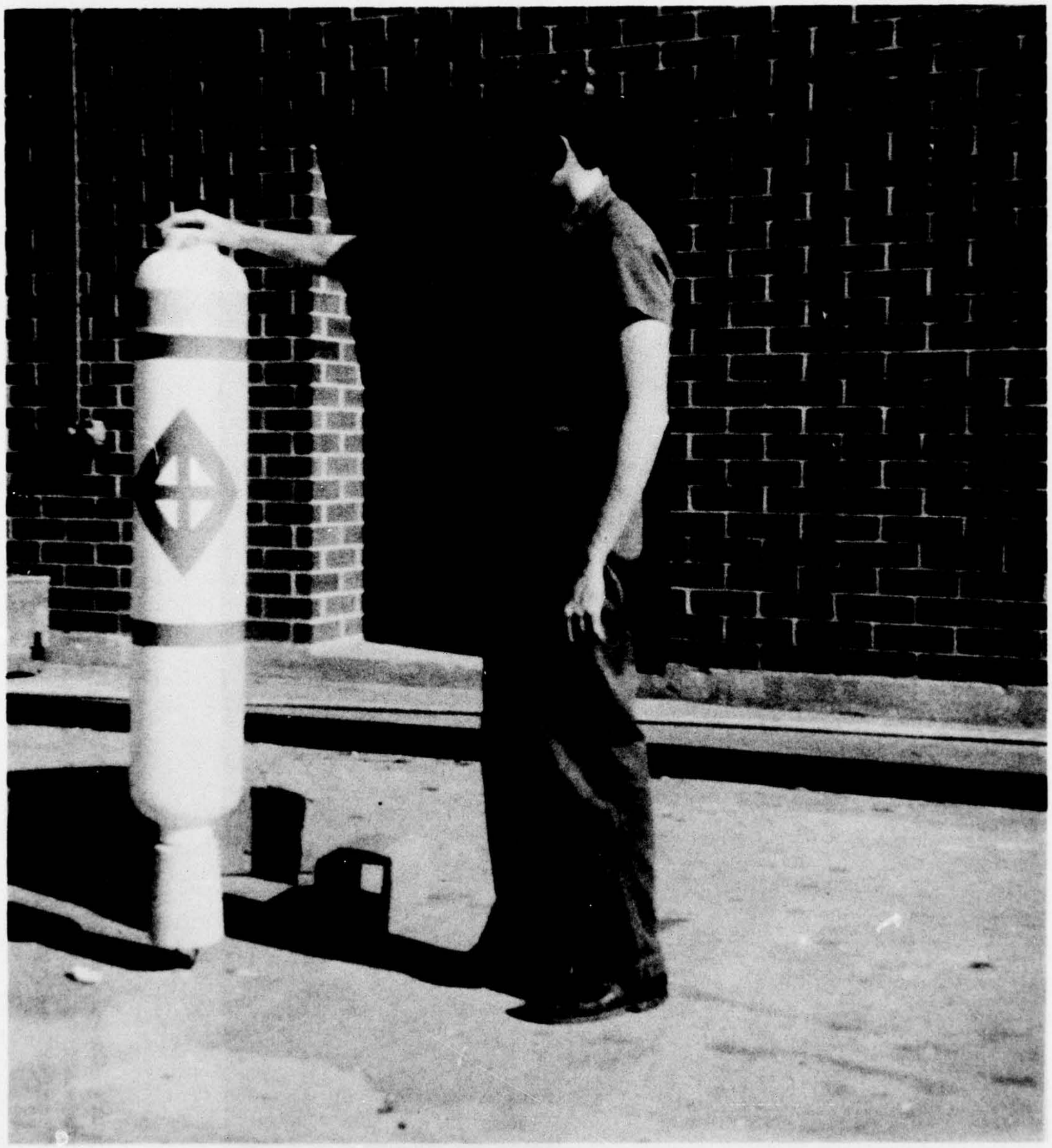


FIGURE 15A

BASIC ROYLAN BUOY BEFORE ADDITION
OF FLOTATION COLLAR

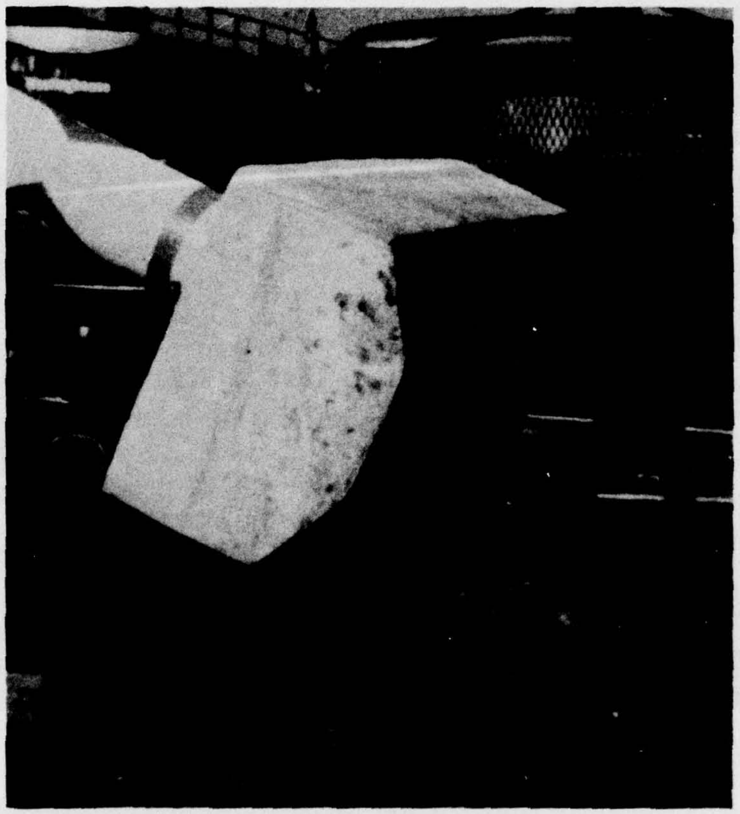


FIGURE 16A

BUOY WITH FLOTATION COLLAR FITTED

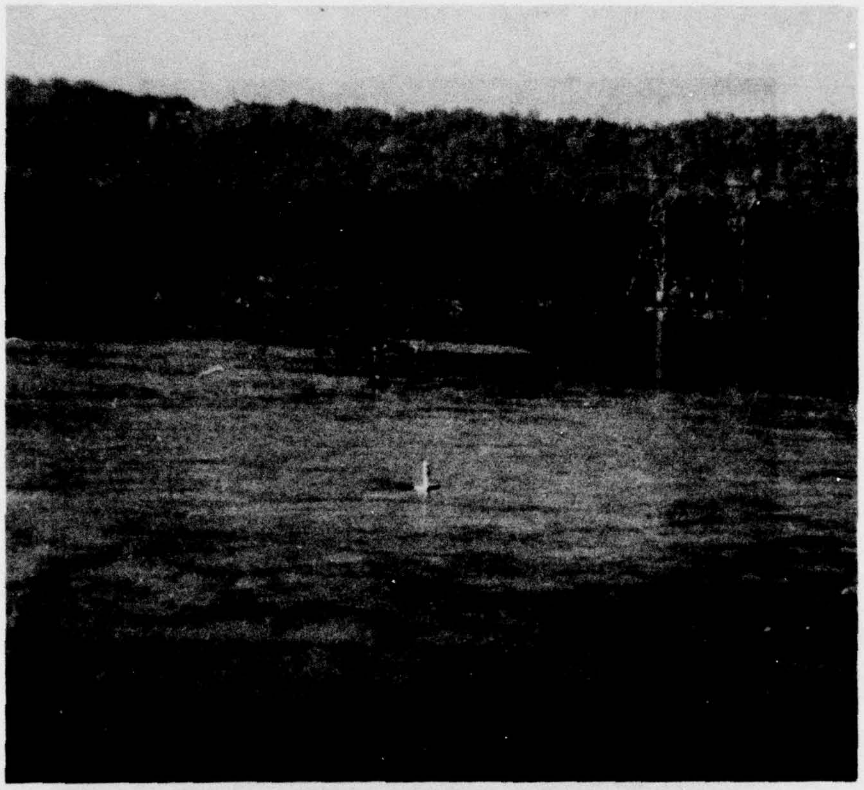


FIGURE 17A

BUOY RIDING IN APPROXIMATELY
FOUR MPH CURRENT

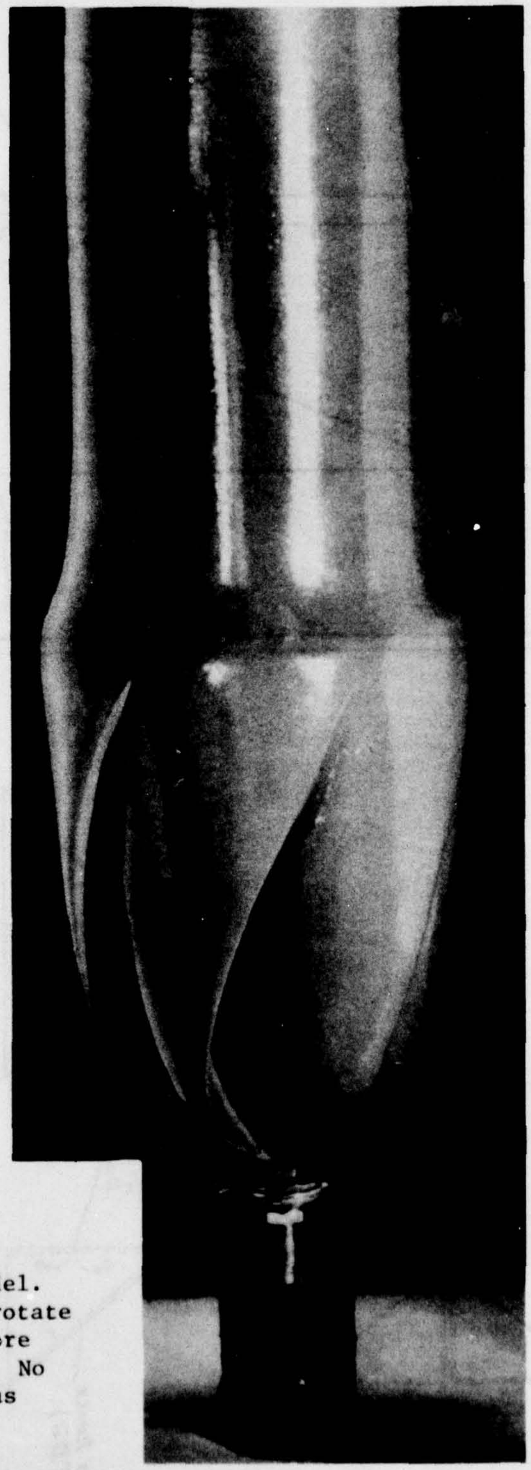


FIGURE 18A

RAMEY ROTATING BUOY

This buoy is a prototype model. The idea is to have the buoy rotate in the current to provide more debris shedding capability. No performance information was available.

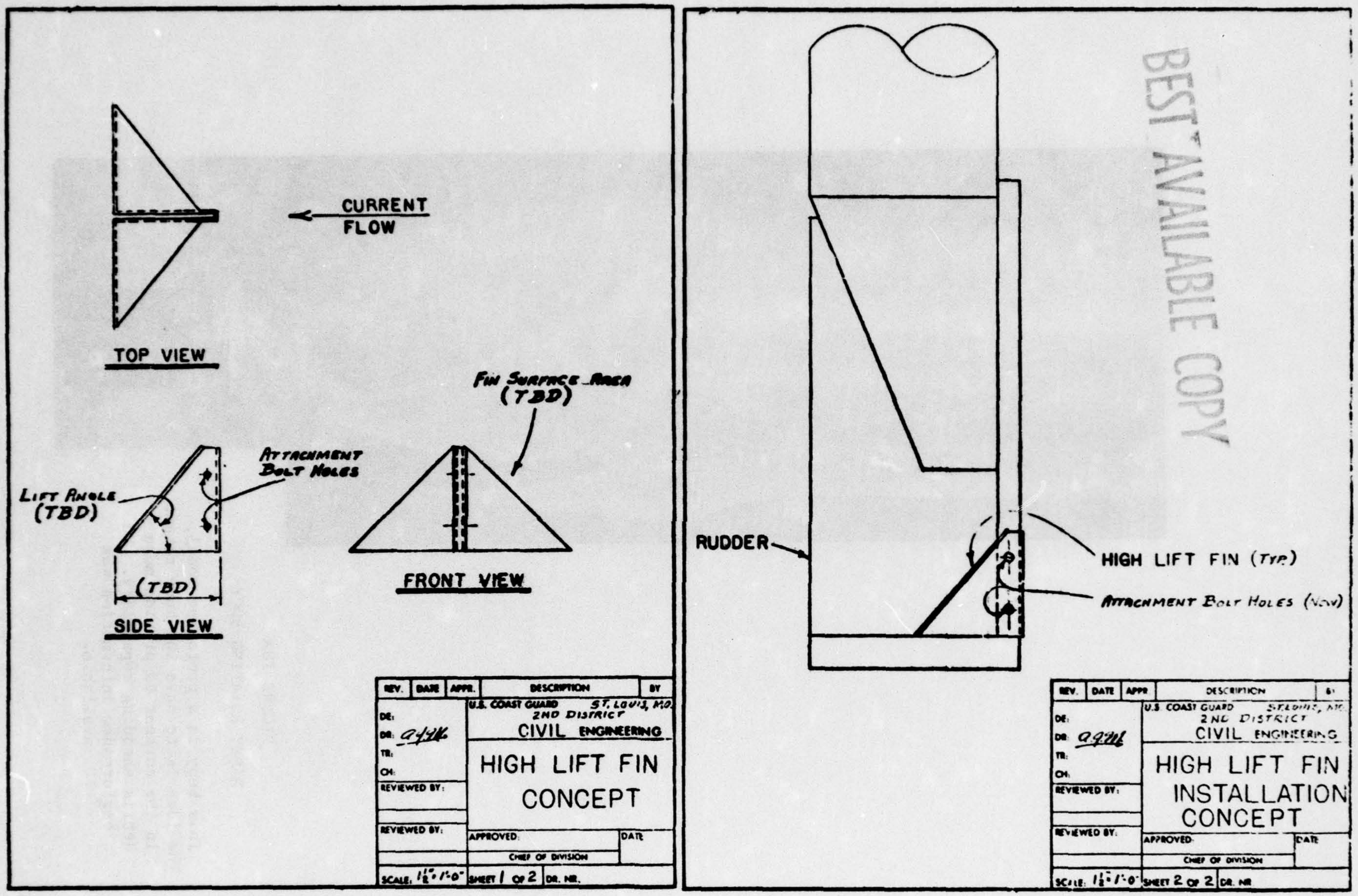
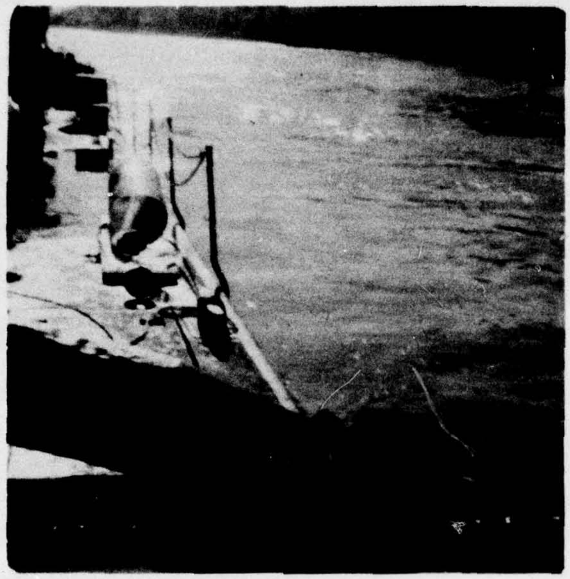


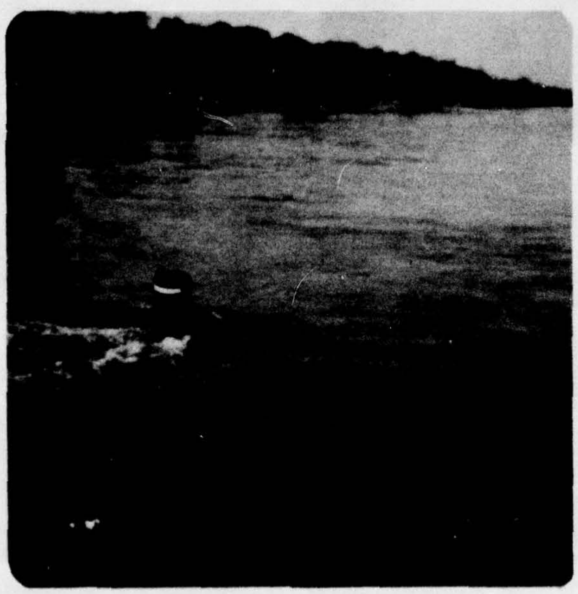


FIGURE 19A

HYDRODYNAMIC LIFTING FINS



(a)

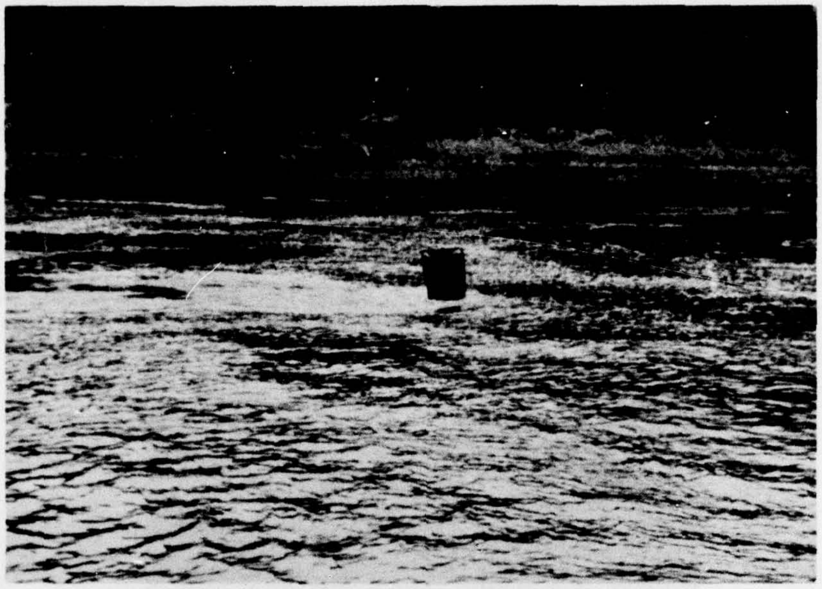


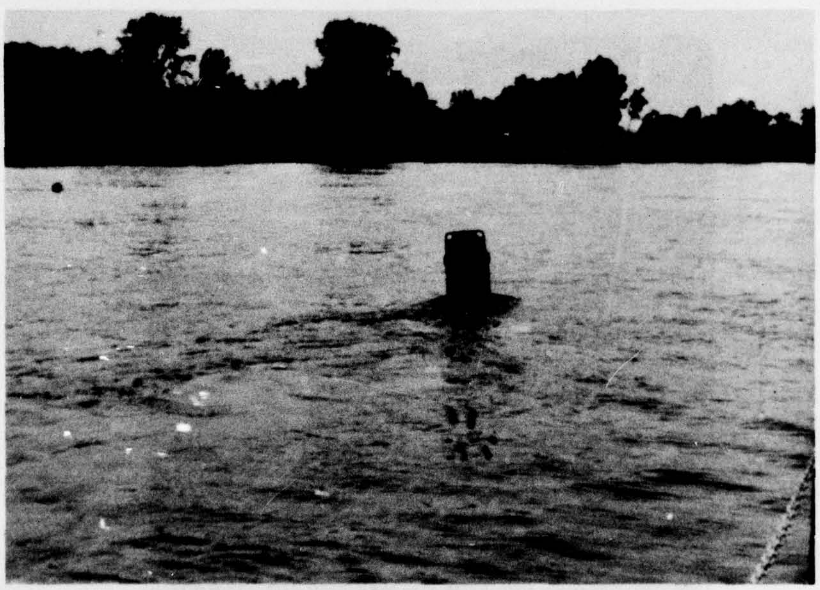
(b)

FIGURE 20A

LIFTING FINS ON A 6TH CLASS BUOY

(a) Shows the hydrodynamic lifting fins mounted on the rudder of a 6th class tall buoy; (b) shows the same buoy in about 4 MPH currents.





(b)

FIGURE 21A

LIFTING FINS ON A 4TH CLASS BUOY

(a) shows a 4th class buoy in approximately 3 MPH current without lifting fins; (b) shows a similar buoy with lifting fins in the same current

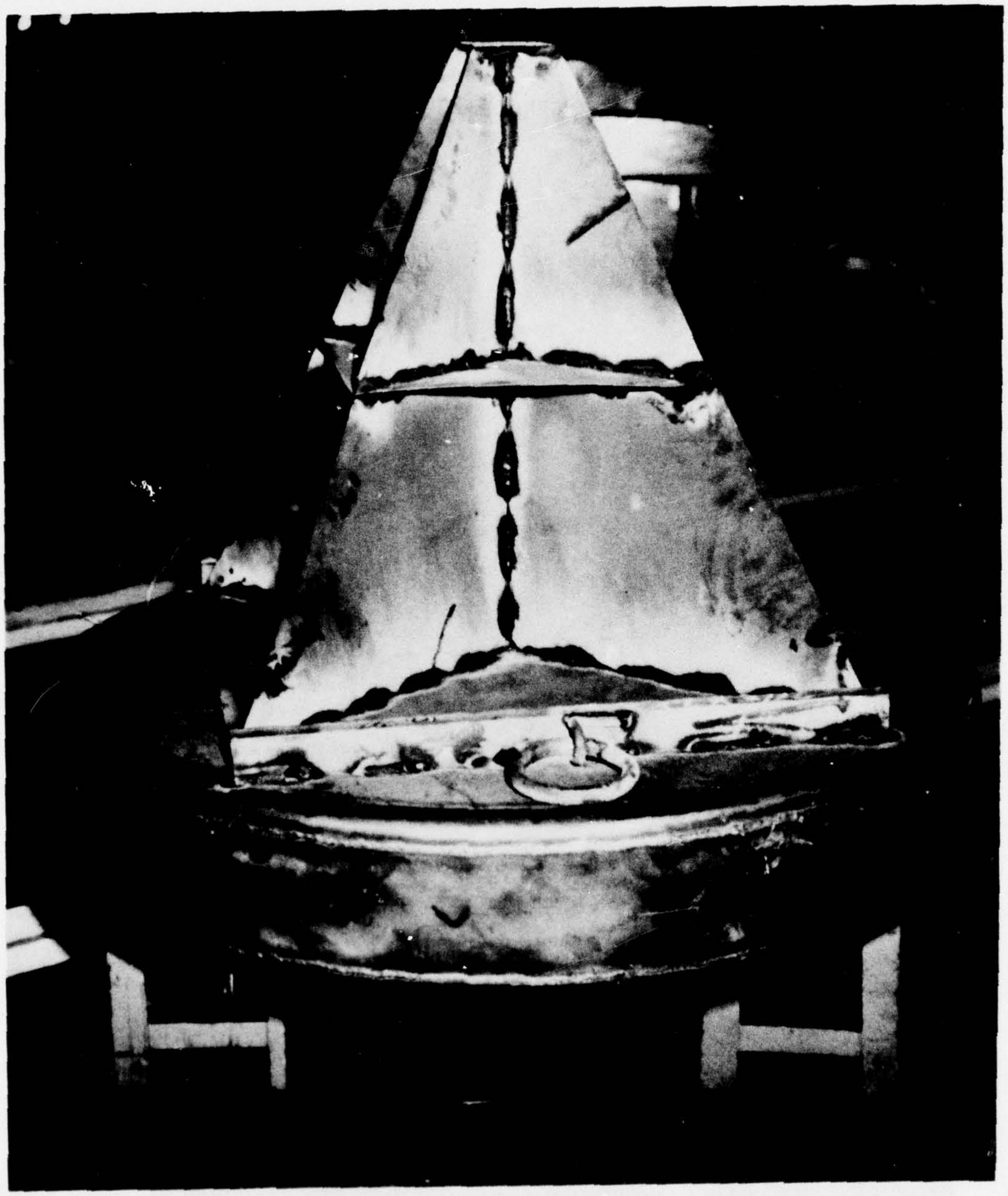


FIGURE 22A

(a) EARLY DISCUS HULL

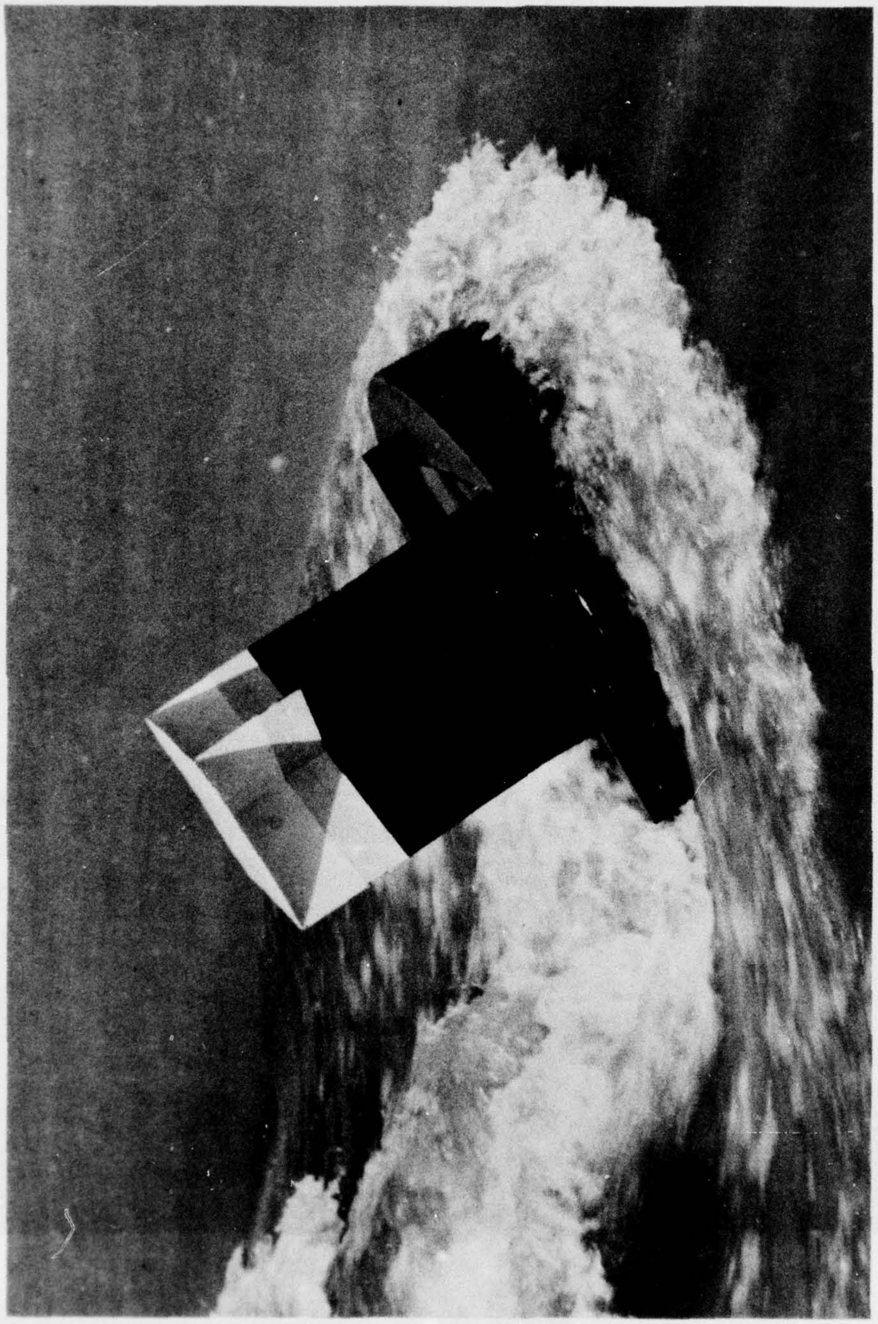


FIGURE 22A

(b) EARLY DISCUS HULL (DEPLOYED)

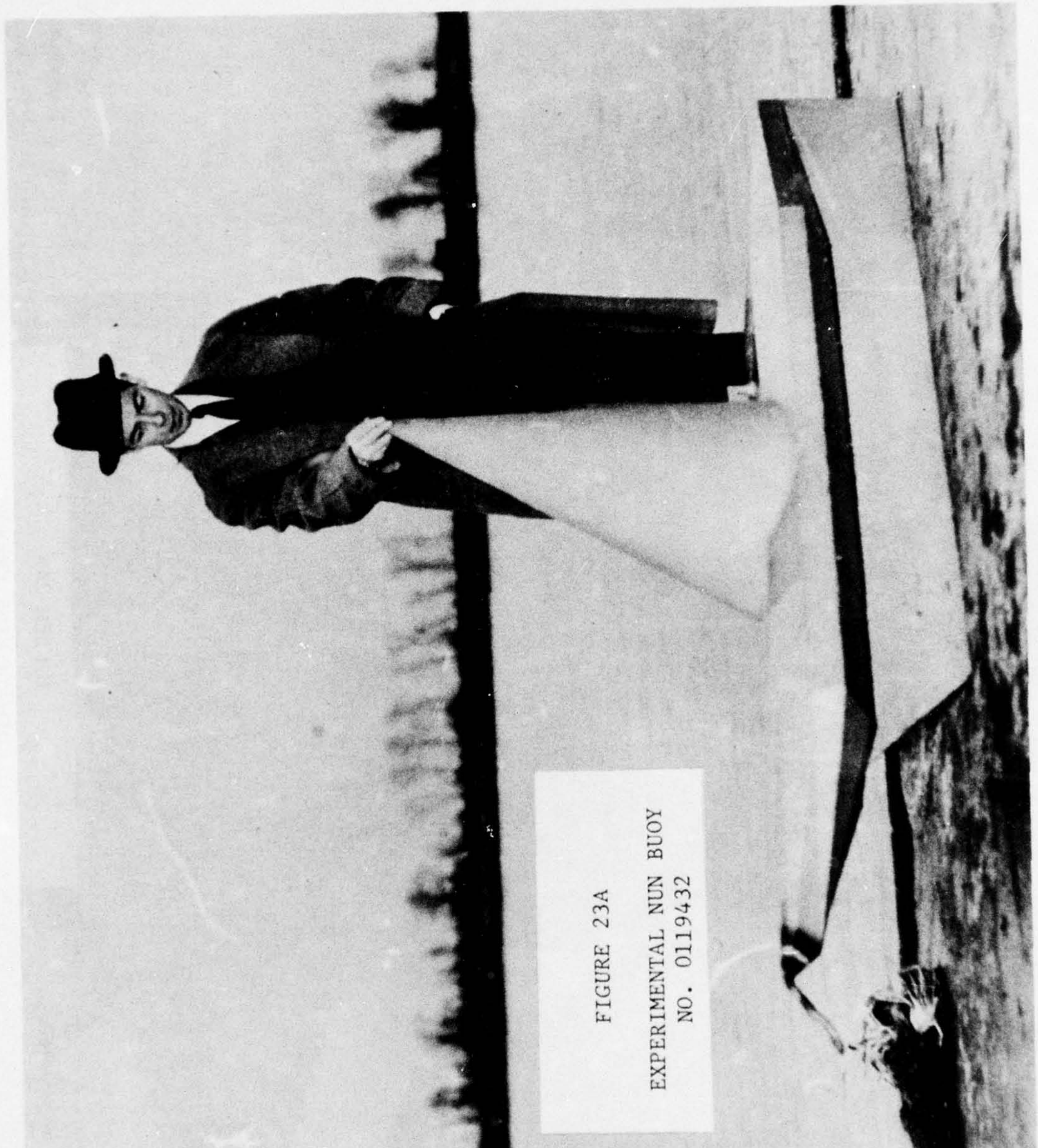


FIGURE 23A

EXPERIMENTAL NUN BUOY
NO. 0119432

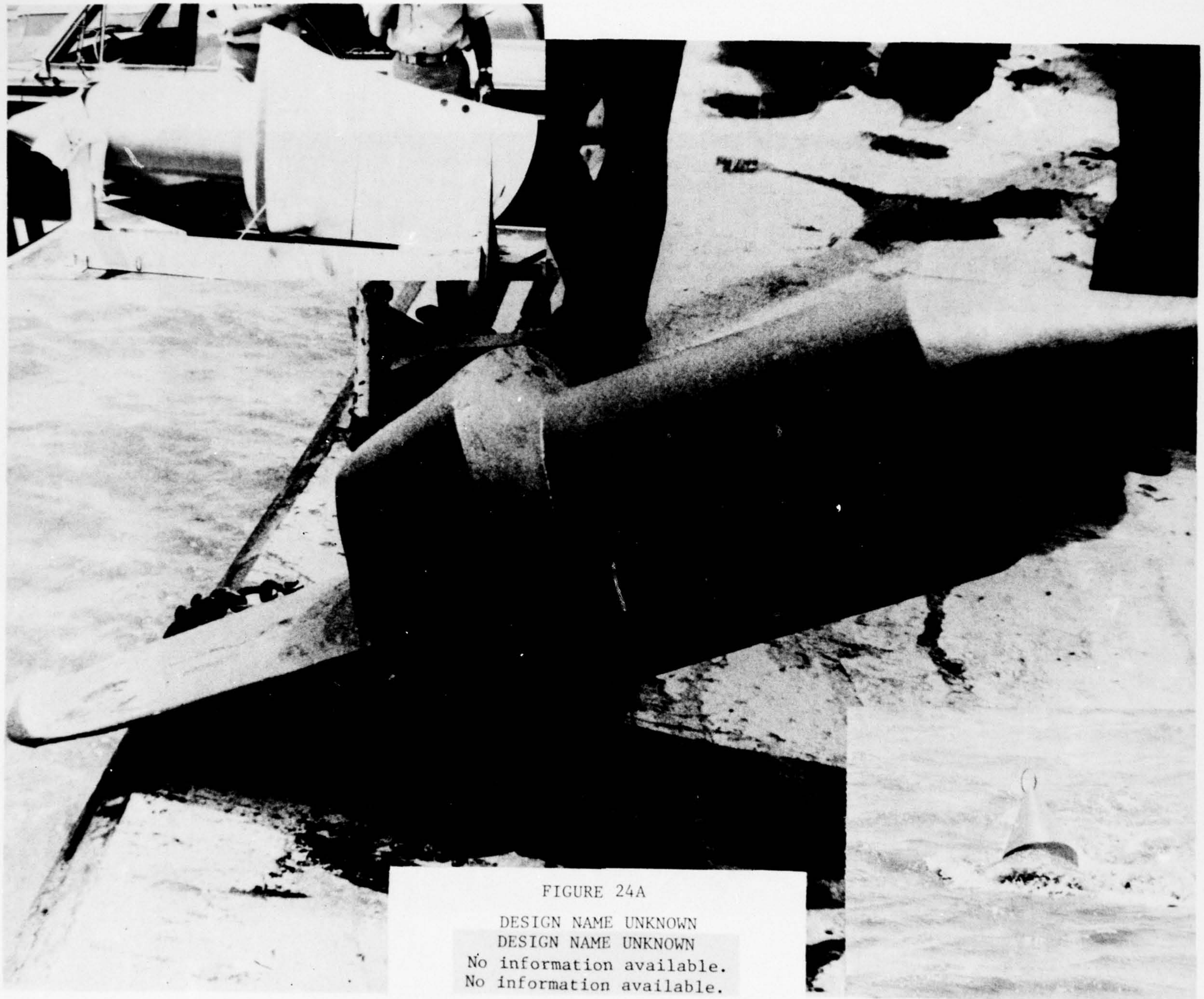


FIGURE 24A

DESIGN NAME UNKNOWN
DESIGN NAME UNKNOWN
No information available.
No information available.

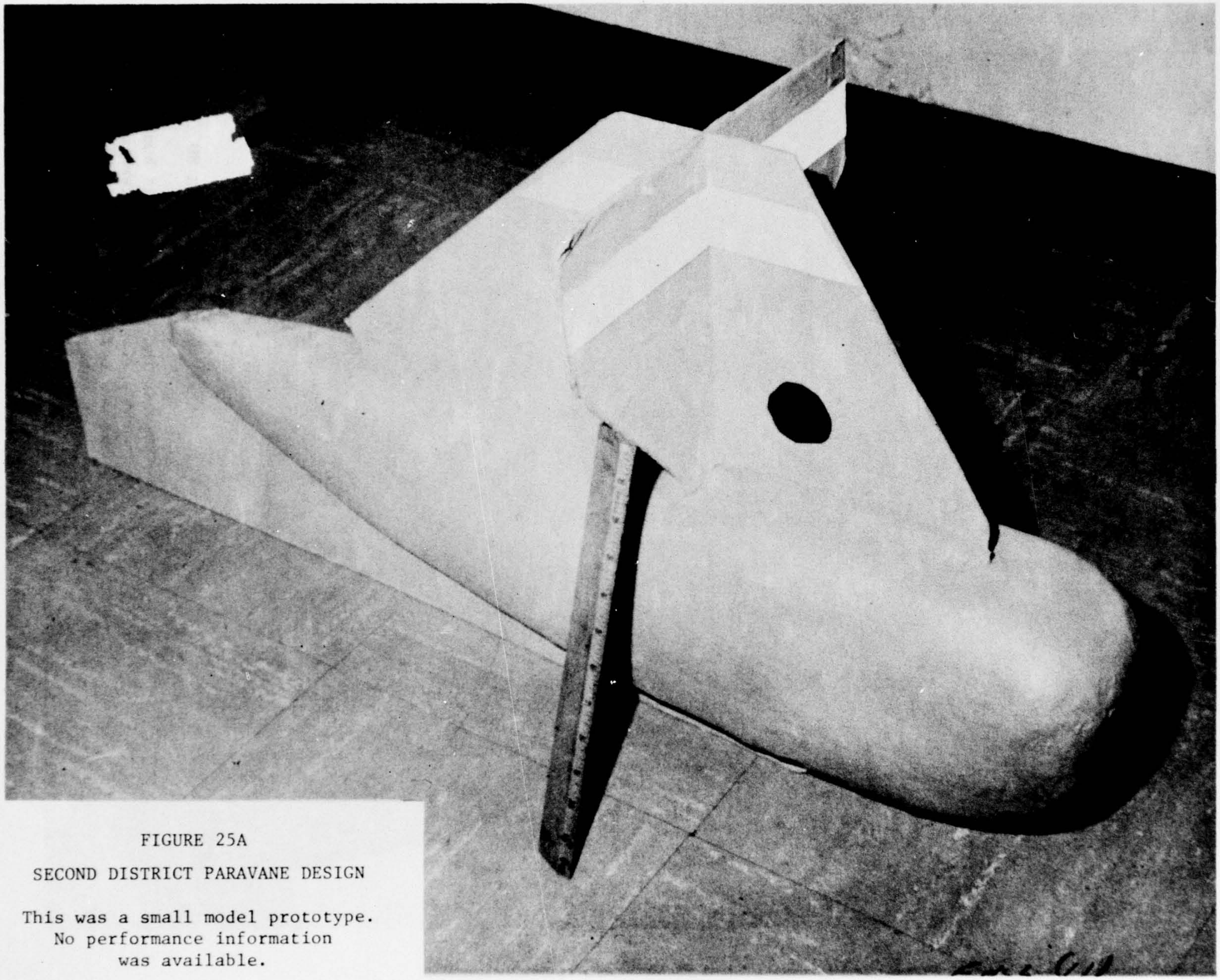


FIGURE 25A

SECOND DISTRICT PARAVANE DESIGN

This was a small model prototype.
No performance information
was available.

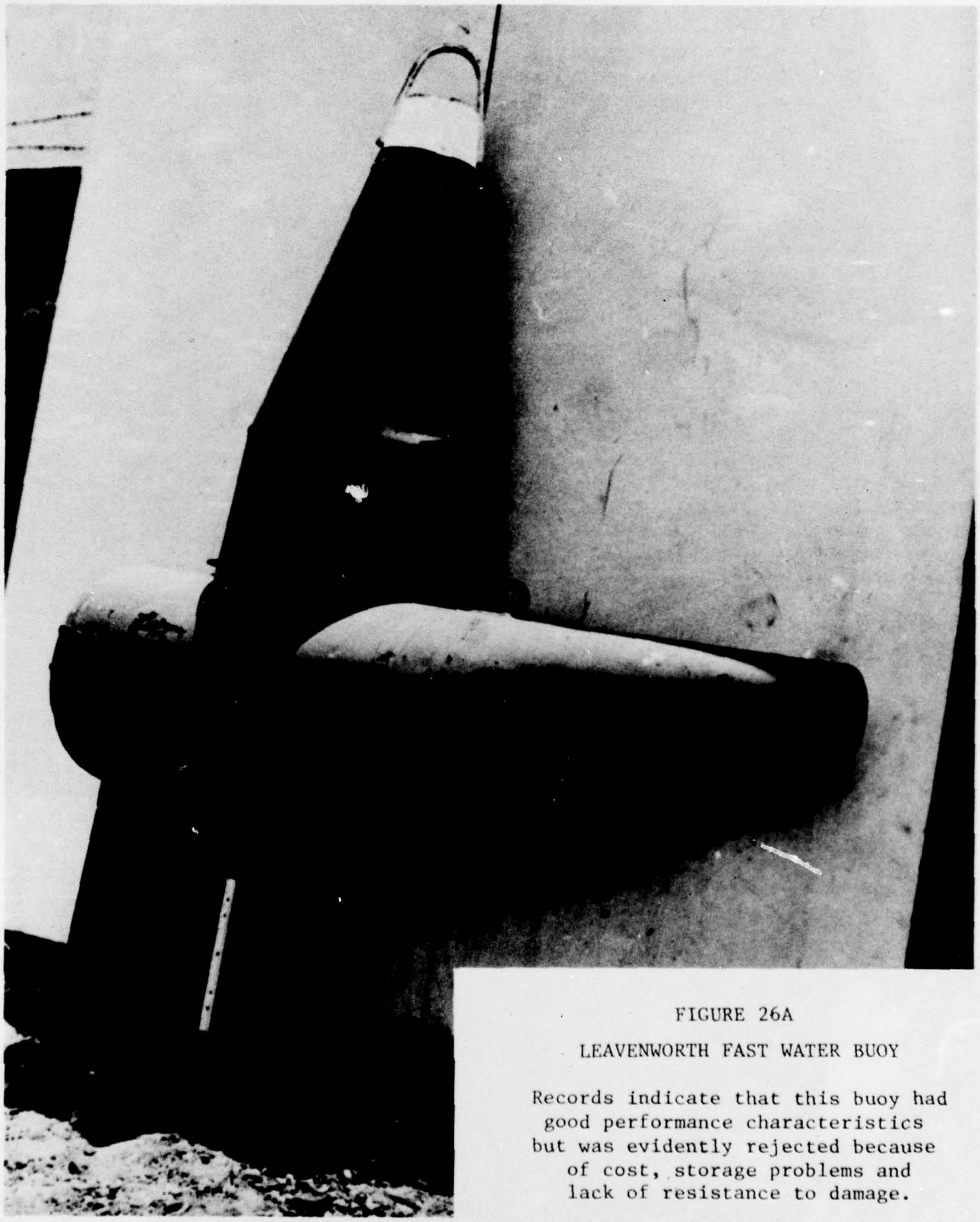


FIGURE 26A

LEAVENWORTH FAST WATER BUOY

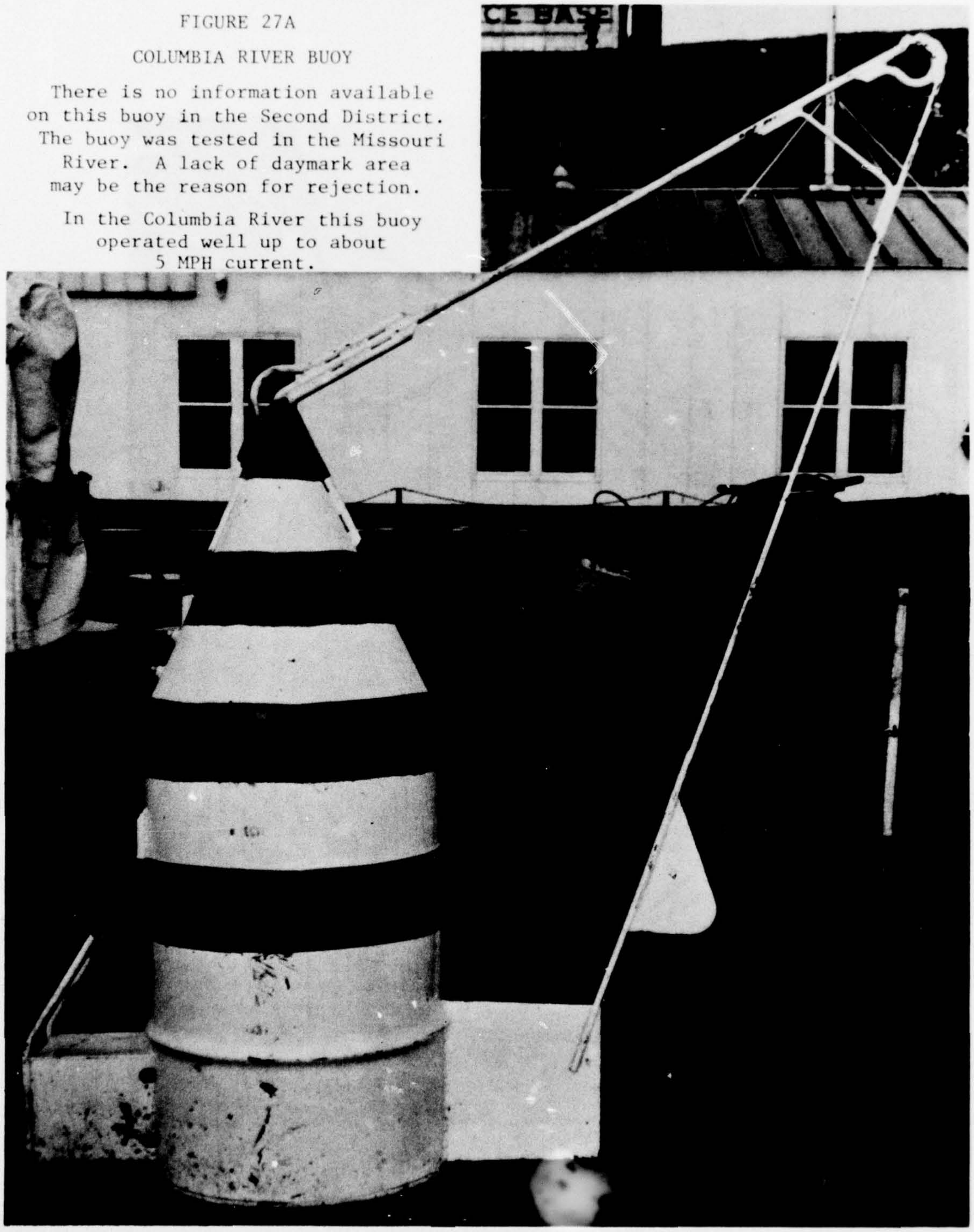
Records indicate that this buoy had good performance characteristics but was evidently rejected because of cost, storage problems and lack of resistance to damage.

FIGURE 27A

COLUMBIA RIVER BUOY

There is no information available on this buoy in the Second District. The buoy was tested in the Missouri River. A lack of daymark area may be the reason for rejection.

In the Columbia River this buoy operated well up to about 5 MPH current.



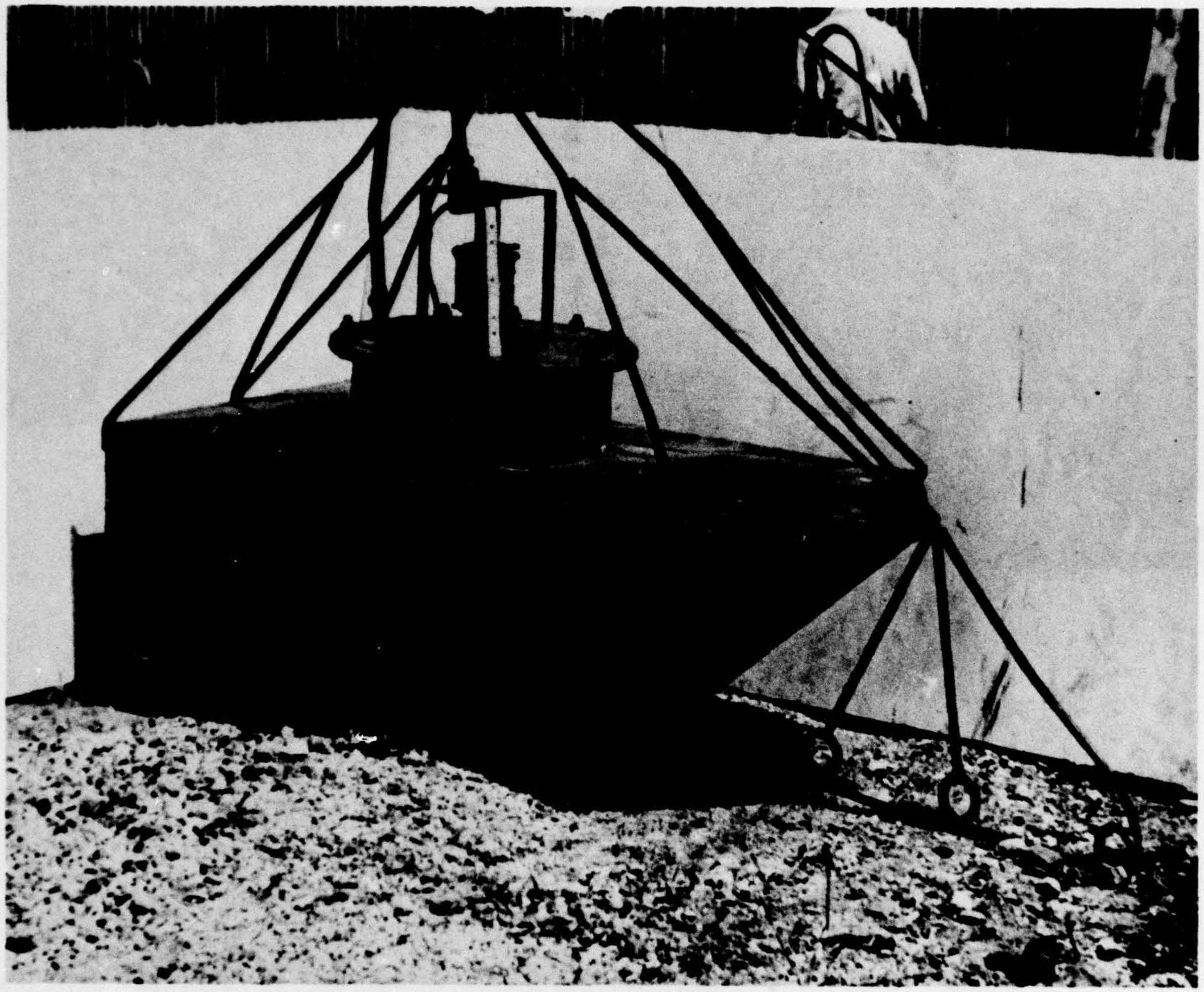


FIGURE 28A - PROTOTYPE LIGHTED BUOY

This buoy was a prototype model using the hull design of the Canadian buoy. No performance information is available.

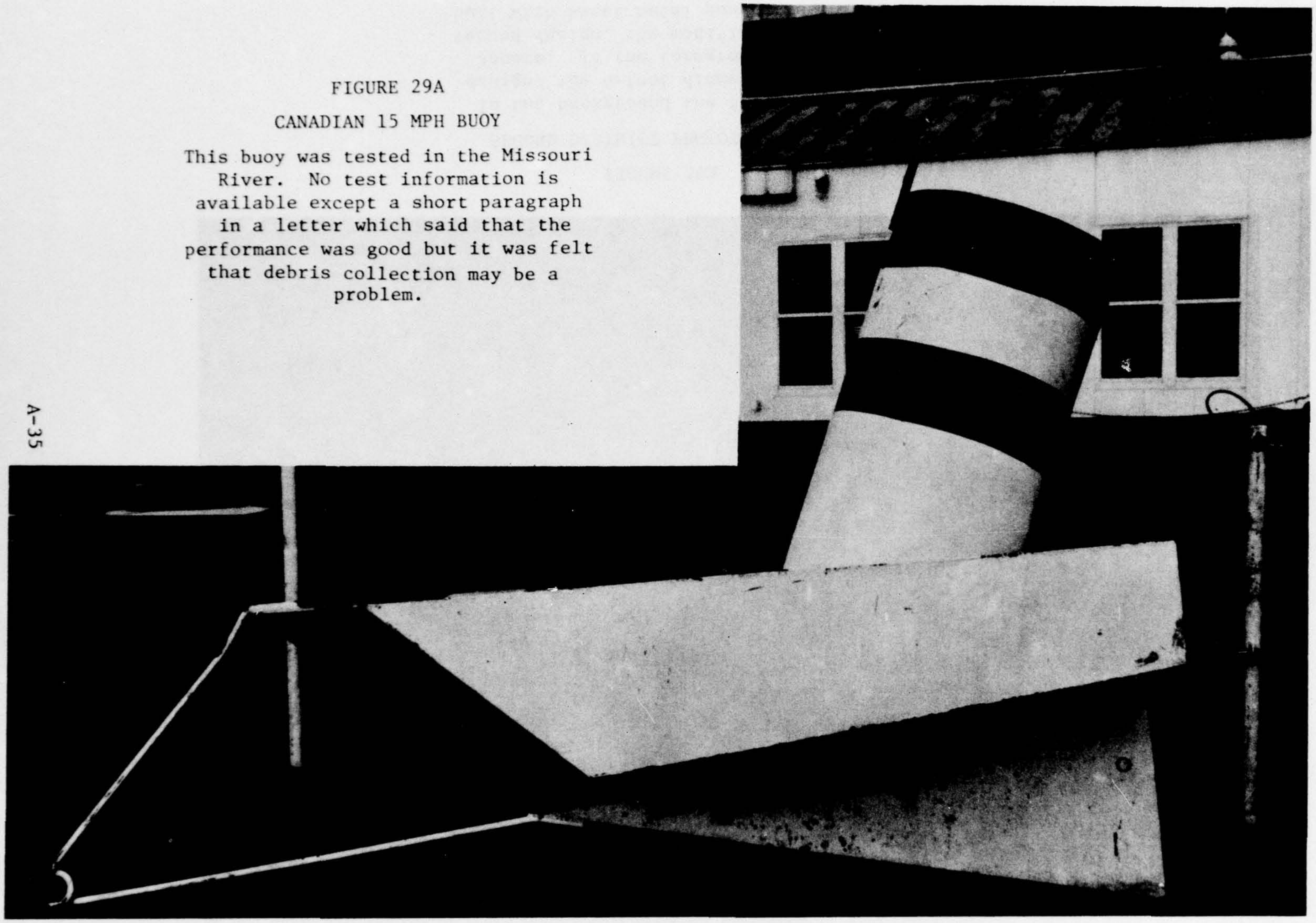


FIGURE 29A

CANADIAN 15 MPH BUOY

This buoy was tested in the Missouri River. No test information is available except a short paragraph in a letter which said that the performance was good but it was felt that debris collection may be a problem.

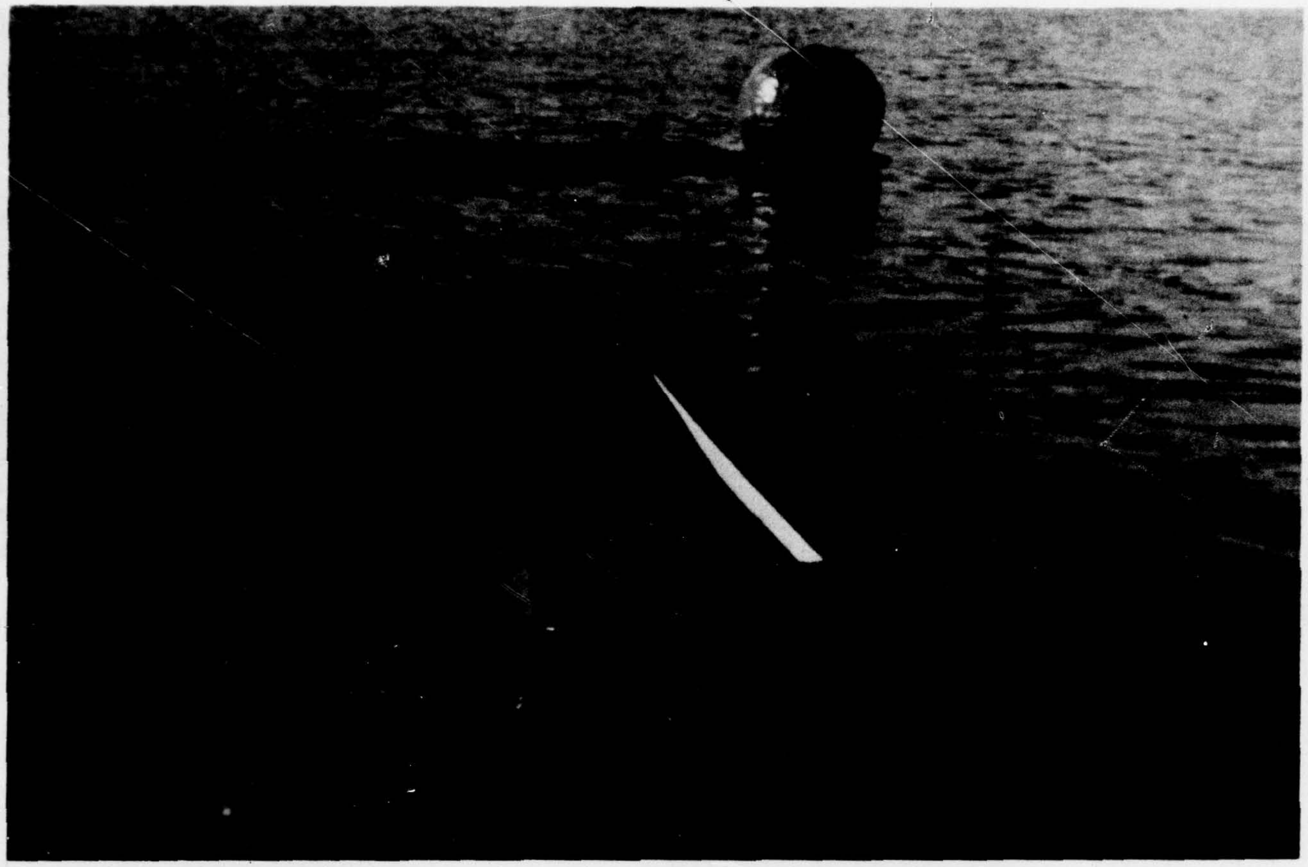


FIGURE 30A

SECOND DISTRICT PROTOTYPE BUOYS

In the background the first buoy design, the 4-foot diameter plastic sphere. In the foreground is the second design, the modified spherical hull with sheet metal superstructure.

FIGURE 31A
GERMAN 5 MPH RIVER BUOY

APPENDIX B
INITIAL PERFORMANCE TESTS

TABLE OF CONTENTS



LIST OF ILLUSTRATIONS

B.1 OBJECTIVES

The Design Study Group (see Section 3.2) selected six hull configurations that potentially met the requirements for a Fast Water Buoy. These hull configurations were:

1. Barge Type Hull (with and without a deep keel)

2. Hemispherical Hull

3. Small Spherical Segment

4. Discus (planing) Hull

5. Teardrop

6. 5th Class Plastic (Cylindrical)

The purpose of the initial performance tests described in this appendix was to observe the performance of these candidate hulls over a range of current velocities, hull displacements, and mooring point locations. The objective was to screen out at an early stage of development those hulls whose performances were not acceptable. In this way, research attention would focus at an early stage only upon those hulls with the highest potential for success.

B.2 PROCEDURE

Test hulls were constructed by Coast Guard personnel, with no emphasis placed upon strength or durability beyond that required for the tests. For the most part, the test hulls were made of plywood and pine strip frames, filled with polyurethane foam, covered with a fiberglass skin.

The hulls were constructed to allow variations in displacement and mooring positions during the tests.

The Upper Mississippi River at St. Louis was selected as the test site. Here, open river conditions prevailed. Hulls were placed in the river and their performances observed and documented with film and slides. As only four mile per hour currents prevailed during the test period, a tow rig was devised that permitted towing the test hulls alongside a river tender to simulate six and eight mile per hour currents. This rig (Figure 1B) worked well for mooring loads up to 700 pounds. Above this point the 500-pound weight would not stay deep enough in the water to simulate the desired mooring scopes. Use of a larger weight was not possible due to existing boom capacities.

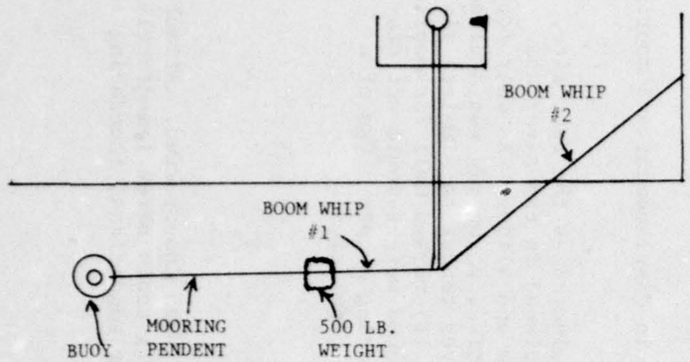
B.3 RESULTS

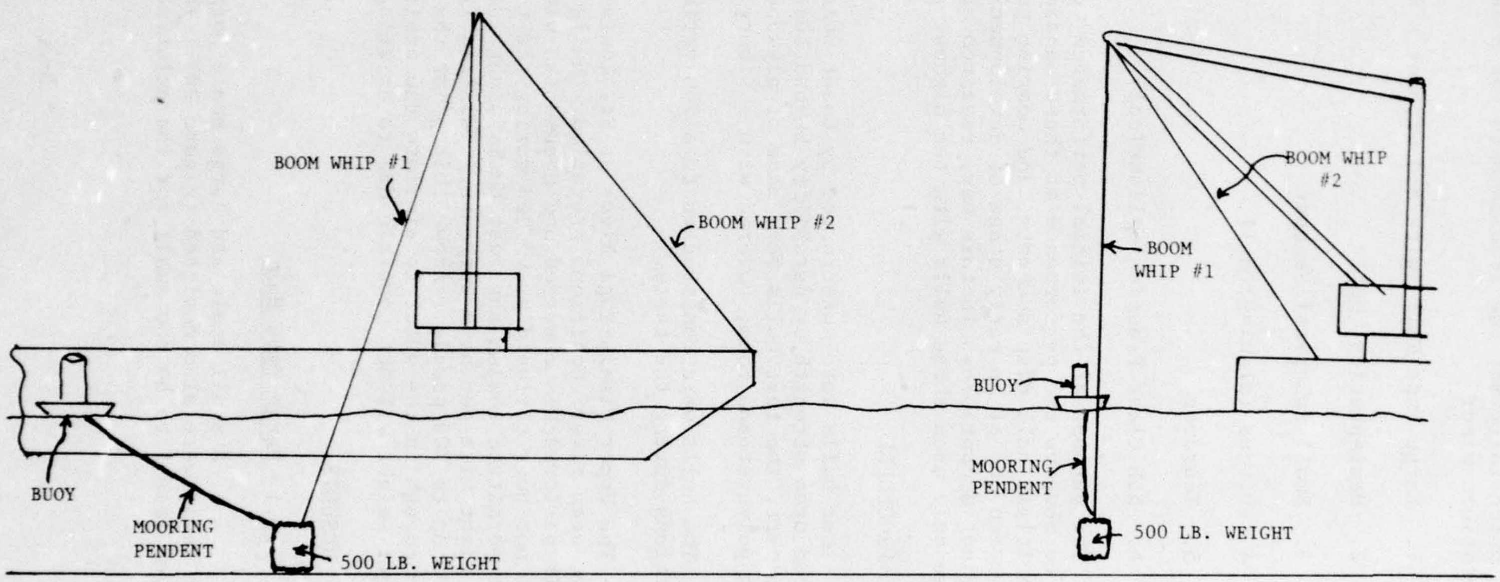
B.3.1 <u>Barge Type Hull</u>

A small scale and large scale barge hull was constructed. Attachable keels were also designed (Figure 2B). The small scale barge immediately proved itself to be too small for the existing river conditions, foundering in

FIGURE 1B

TOWING RIG



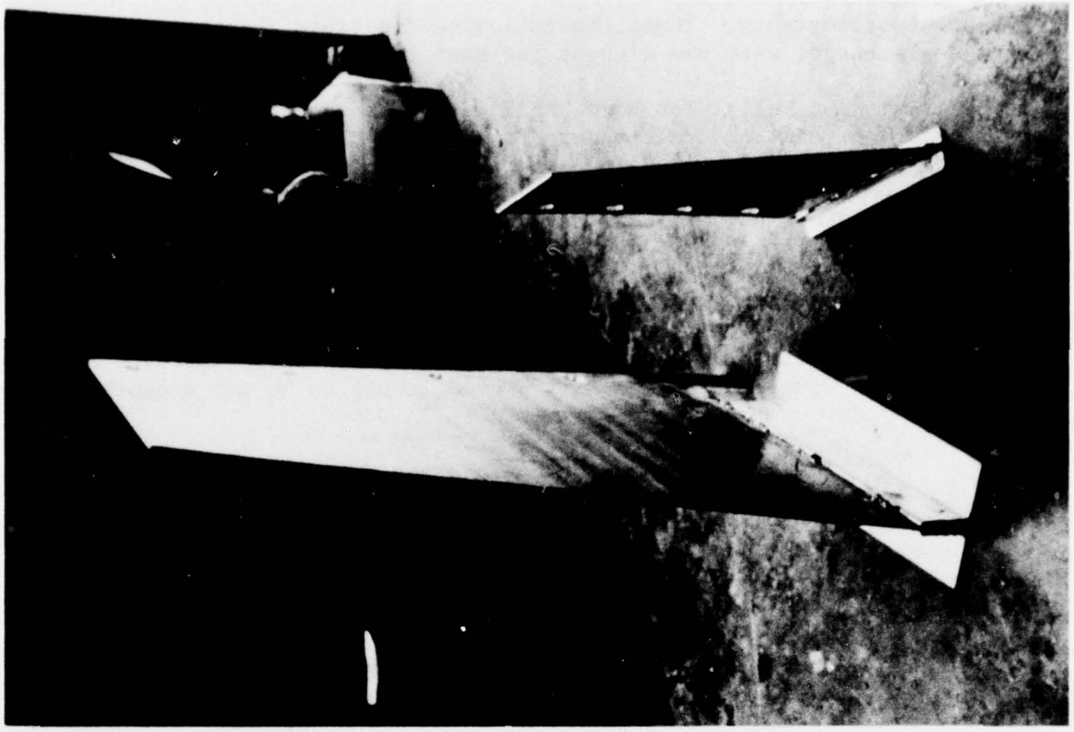


FIGURE 2B - ATTACHABLE KEELS, FOR SMALL SCALE AND LARGE SCALE TEST HULLS

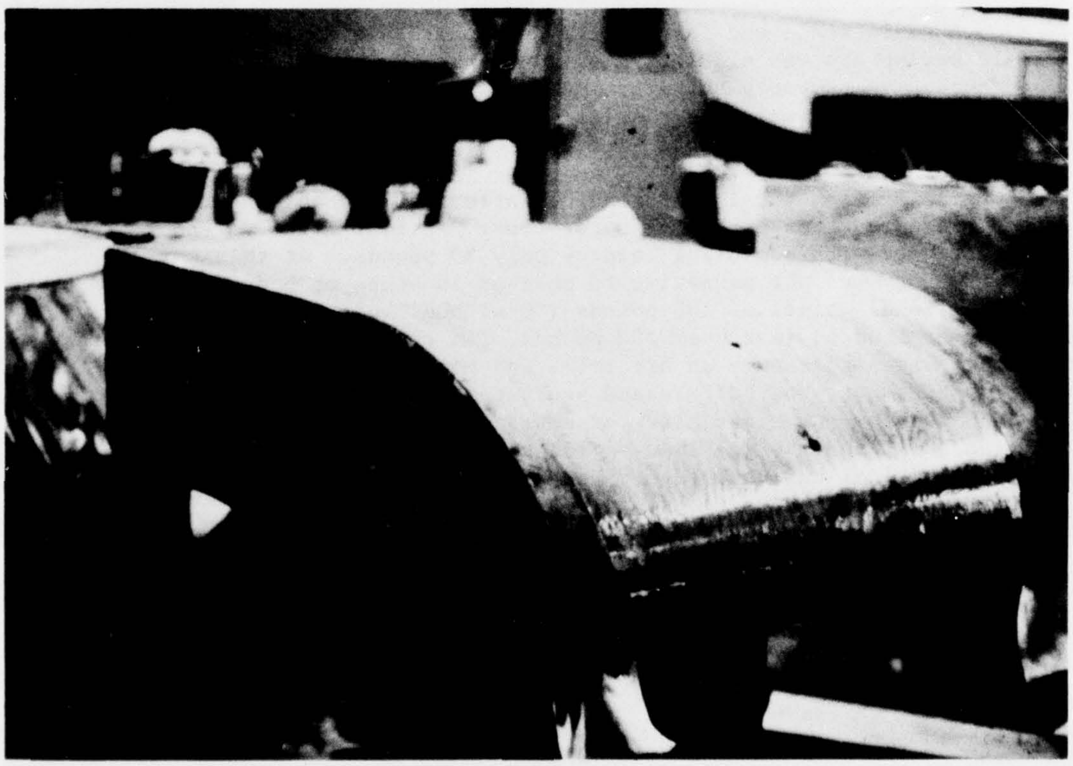


FIGURE 3B - LARGE SCALE BARGE HULL

four miles per hour currents. Thus, the following describes the test results for a large scale barge, with and without the keel (Figures 3B and 4B).

1. Without Keel: The barge hull without a keel performed inadequately. At mooring point 1 and at a scope of 6:1, the hull rode upright in currents of 3.5 miles per hour, but it turned athwartships to the current and its deck became awash (Figure 5B). Changing the mooring point (to mooring point #2) did not improve performance. At a scope of 6:1, in currents of 4.1 miles per hour, the hull rode bow down with its decks awash (Figure 6B). At the same time, the hull developed mooring loads of 175 pounds, which is significantly higher than the mooring load of a barge with a keel attached.

2. With Keel: The addition of a keel significantly improved barge hull performance. However, the barge hull proved itself to be not acceptable for two reasons:

(a) The size of the mooring load was extremely sensitive to mooring point. Figure 7B shows a large scale barge with deep keel moored at mooring point 5, displaying adequate performance with a mooring load of 60 pounds, in a four mile per hour current. However, changing the mooring point to #7, the barge hull tipped upon its side, and the mooring tension increased to 350 pounds. This sensitivity was not acceptable.

(b) The non-axisymetric hull shape was easily skewed into the current by debris, causing the barge hull to sail into the channel or toward the bank and ultimately sink. Such performance was not acceptable.

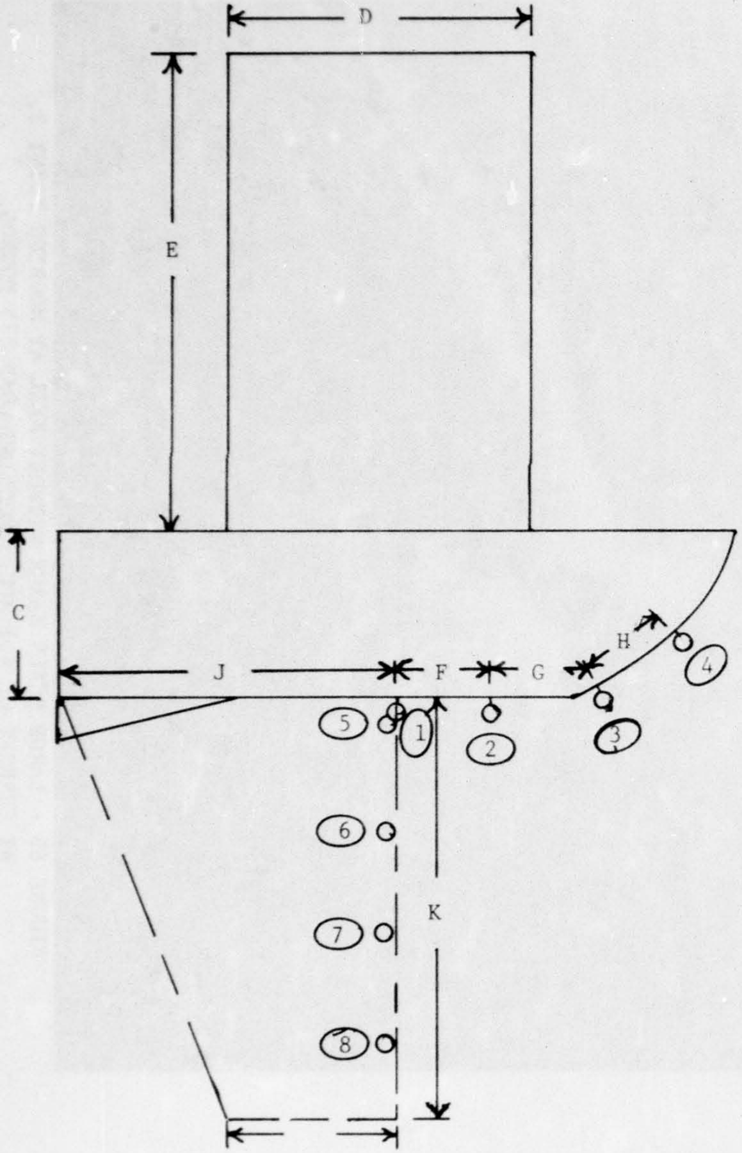
### B.3.2 Hemispherical Hull

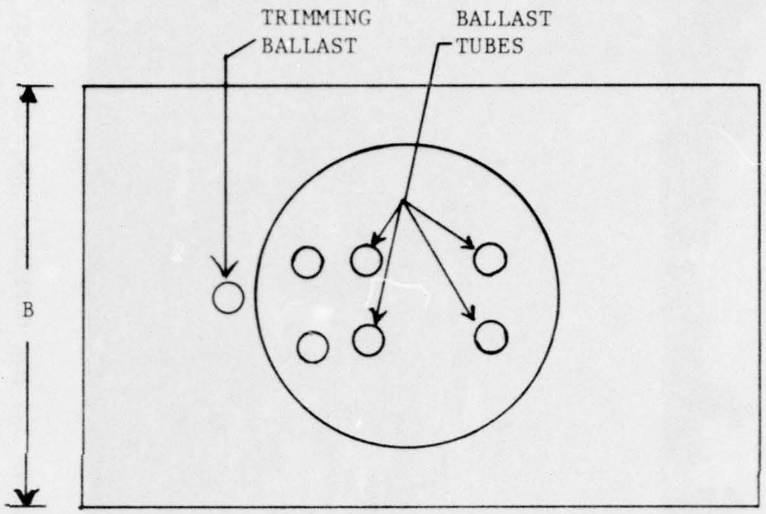
A small scale and large scale hemisphere was constructed. The small scale hemisphere was eliminated early in the tests because it did not have enough reserve buoyancy to withstand even slight debris buildup. Thus, the following describes the test results of the large scale hemisphere only. Figure 8B shows the test hull which weighed 105 pounds.

The hemispherical hull remained afloat throughout the range of currents between four and eight miles per hour. At four miles per hour, the hull rode upright, with a mooring load of only 50 pounds. At this current velocity, the buoy was not sensitive to changes in scope or buoy weight, although additional weight of 100 pounds (total buoy weight 205 pounds) increased mooring load to just over 100 pounds. As the current velocity increased, the buoy hull began to assume an aft trim, and mooring load increased significantly. At six miles per hour, the hull leaned against the current, with a mooring load of about 450 pounds. At eight miles an hour, a head wave had developed at the front of the hull, and mooring load approached 800 pounds. However, at no time did the hemispherical hull submerge. Because of this trait, the hemispherical hull was selected for future tests.

FIGURE 4B

BARGE HULL




| | FULL SCALE | HALF SCALE |
|---|---|---|
| A | 4'0" | 2'0" |
| B | 2'6" | 1'3" |
| C | 1'0" | 0'6" |
| D | 1'10" | 1'0' |
| E | 2'10" | 1'4" |
| F | 9" | 4" |
| G | 8" | 4" |
| H | 7" | 4" |
| J | | |
| K | 3'0" | 1'6" |
| L | 1'0" | 6" |
| LIGHT WEIGHT | 105 LBS. | 20 LBS. |
| KEEL WEIGHT | 20 LBS. | 2.5 LBS. |
| TRIMMING BALLAST | 35 LBS. | 5 LBS. |

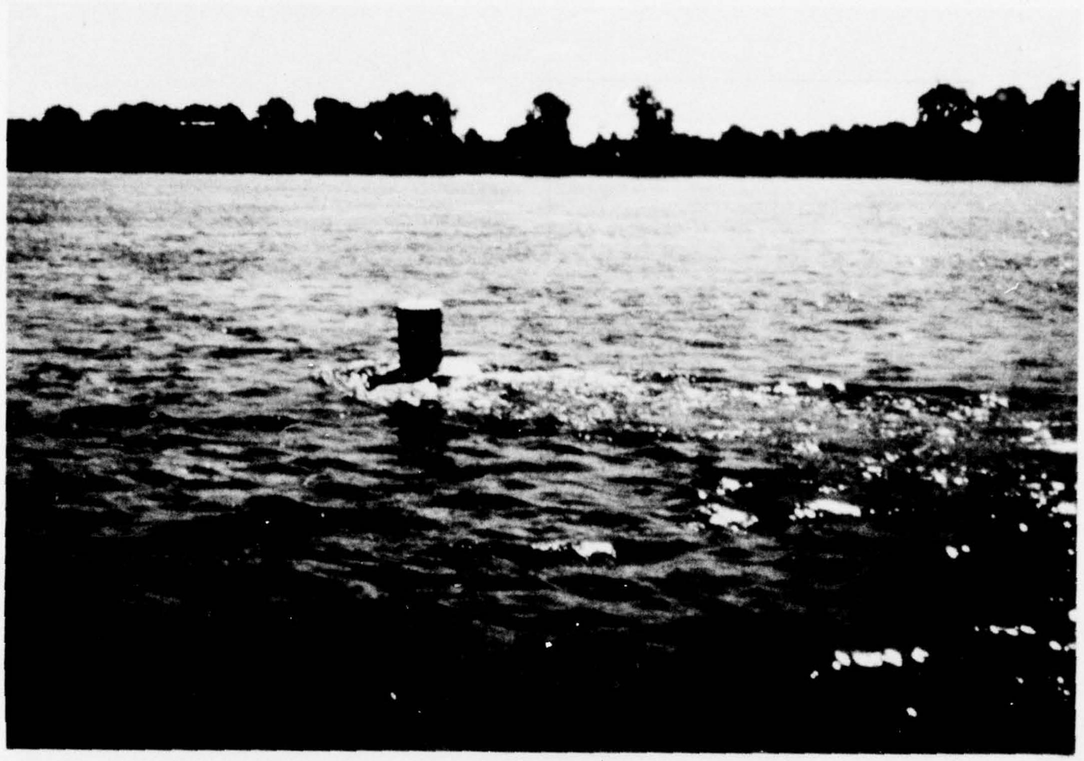


FIGURE 5B - LARGE SCALE BARGE WITHOUT KEEL IN 3.5 MPH CURRENTS (MOORING POINT 1)

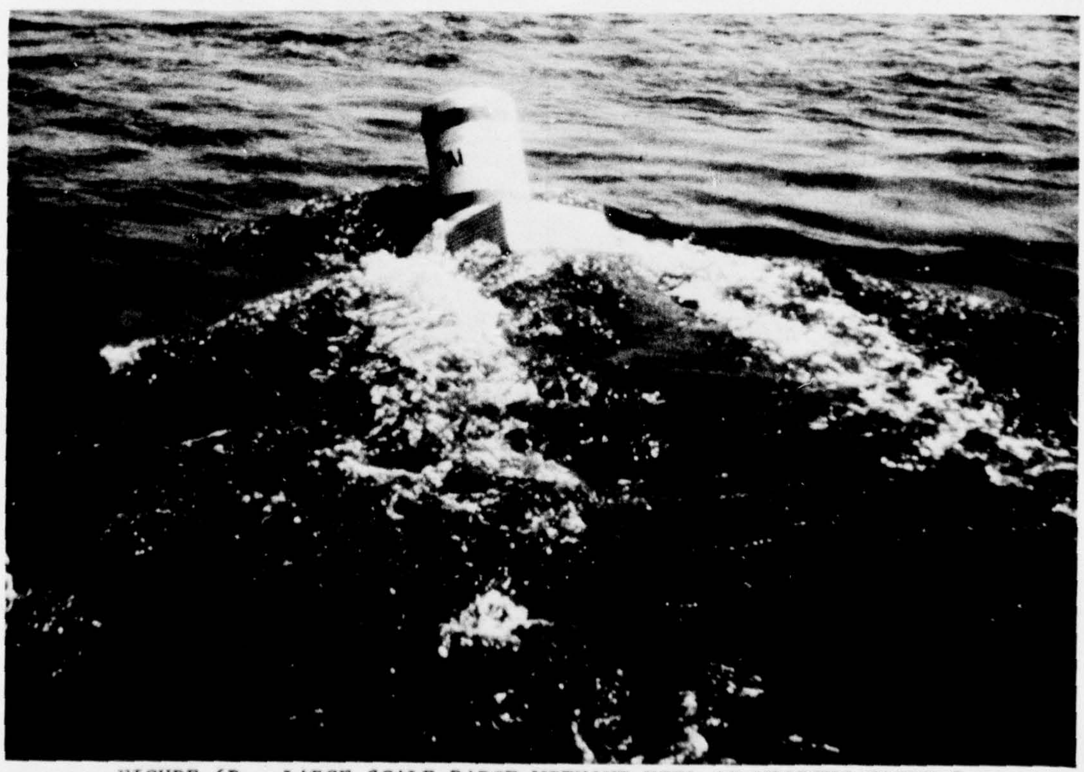


FIGURE 6B - LARGE SCALE BARGE WITHOUT KEEL AT MOORING POINT 2,
AT CURRENT OF 4.1 MPH. MOORING LOAD 175 POUNDS.

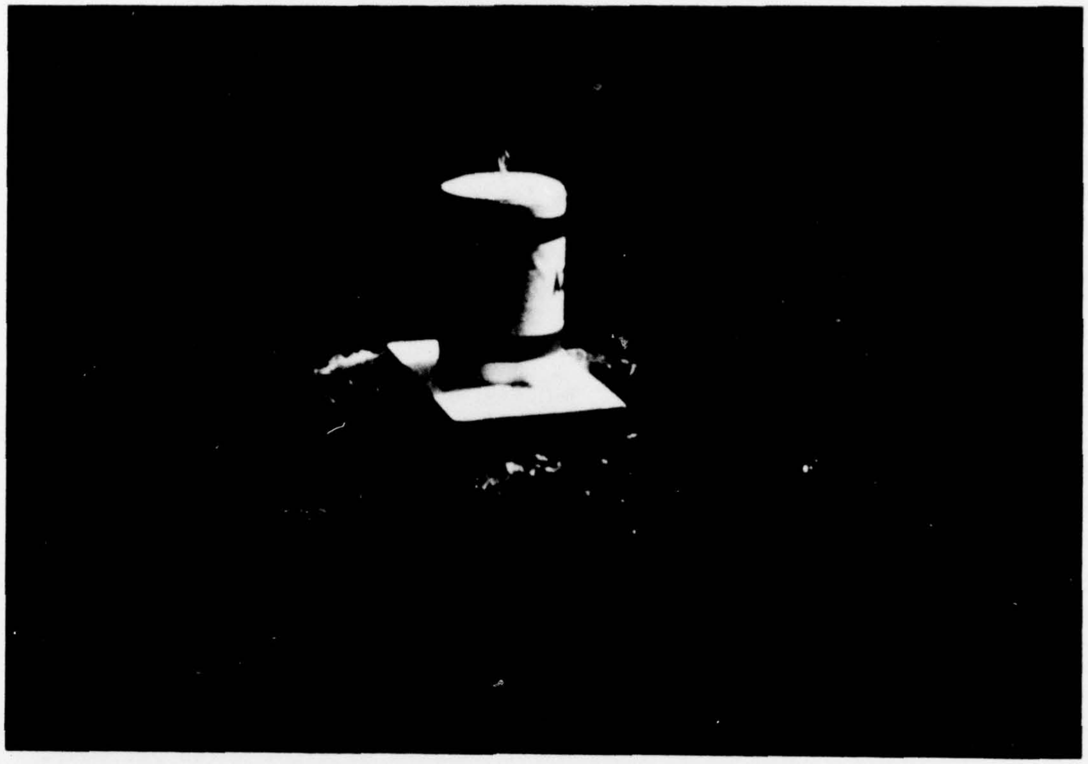


FIGURE 7B - LARGE SCALE BARGE WITH DEEP KEEL AT MOORING POINT 5 IN 4 MPH CURRENT

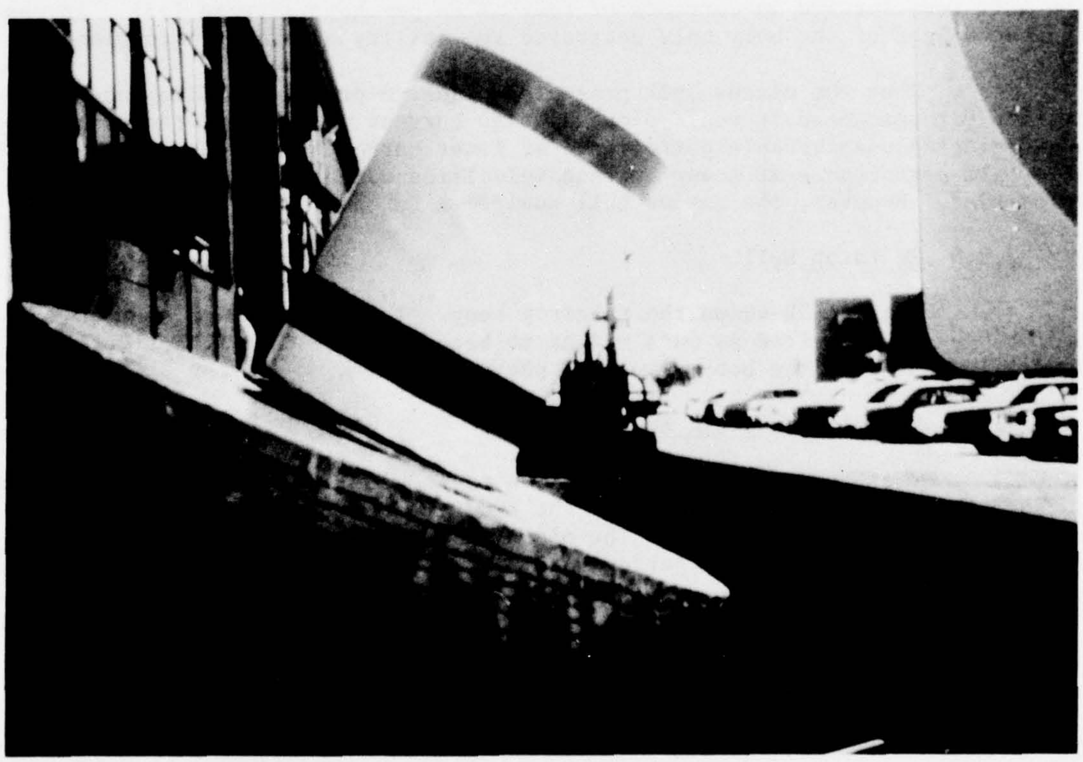


FIGURE 8B - LARGE SCALE HEMISPHERE

B.3.3 Small Spherical Segment Hull

Figures 9B and 10B show the design of the spherical segment hull. Performance of this buoy proved unsatisfactory. At current velocity of four miles per hour, the hull created mooring loads that ranged between 35 and 125 pounds, depending upon the mooring point. But even at 35 pounds' tension, the buoy leaned with the current, with its after deck awash. As the mooring load increased, performance deteriorated, and the hull eventually submerged.

B.3.4 Discus Hull

A large scale and small scale discus hull was constructed. However, as with other small scale prototypes, the small scale discus floundered in four mile per hour currents, and further tests were abandoned. The following describes the performance of the large scale discus only. See Figure 11B which shows the hull design.

The purpose of testing a discus hull was to discover whether a planing type hull would fulfill the requirements for a fast water buoy. The results of the tests were cautiously optimistic. The discus buoy would plane, but only during very limited circumstances. The 113-pound discus moored at position number 1 would not plane in four mile per hour currents, but nevertheless it did ride upright and developed only a 50-pound mooring load (Figure 12B). As the current velocity increased, the buoy refused to plane and developed an aft trim (Figure 13B), and at a current of eight miles per hour, the mooring load had increased to 425 pounds. By changing the mooring position to point 2, the 113-pound hull would plane at higher velocities, and the mooring tension would level off at only 100 pounds. However, when moored at point 2, the hull rode forward in currents of four miles per hour (Figure 14B). Increasing the weight of the buoy only destroyed the ability of the hull to plane.

Thus the discus hull presented a design problem. While under certain circumstances it would plane at high current velocities, the same hull would display unacceptable performance at lower current velocities. An acceptable hull performance at lower current velocities would not plane at higher velocities. However, the discus hull qualified for further tests.

B.3.5 Teardrop Hull

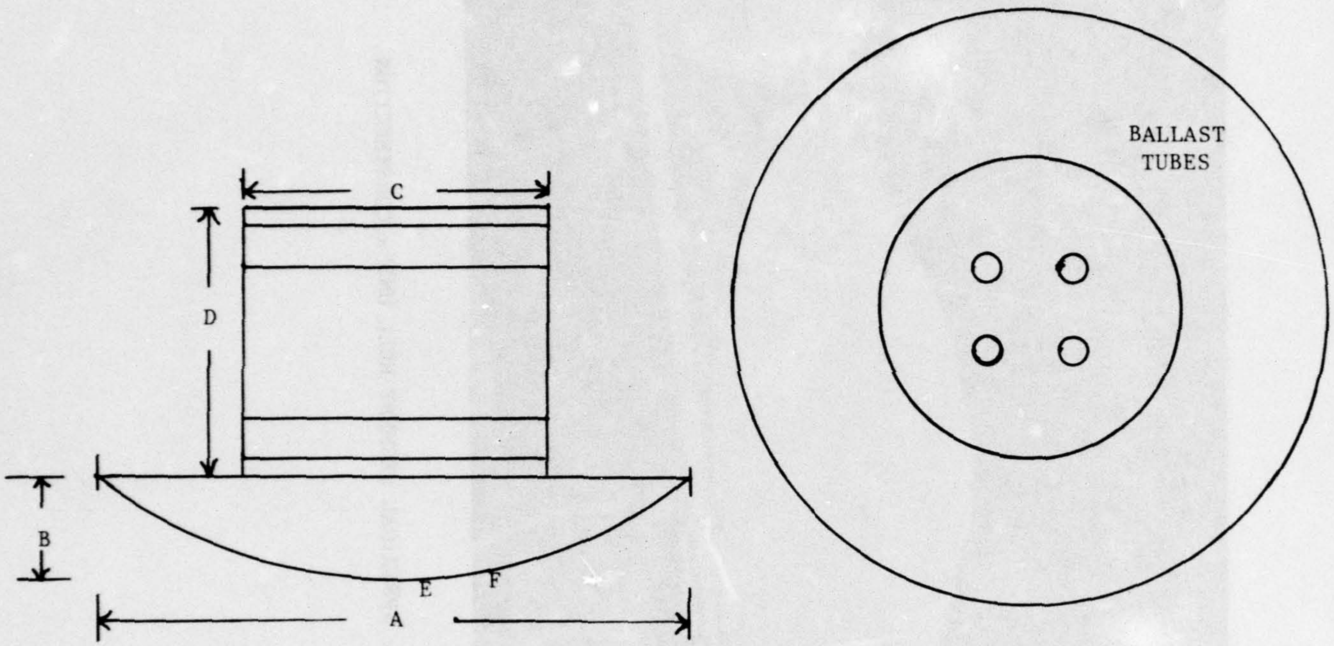
Figure 15B shows the teardrop buoy. This hull design was not acceptable. It required so much weight to become stable that in currents of four miles per hour the buoy dived and porpoised.

B.3.6 5th Class Plastic Buoy

The 5th class plastic buoy was included in the tests for comparison purpose, to gauge the performance of the experimental hulls with that of a conventional cylindrical shape. The discus and hemispherical hulls proved themselves to be superior in performance to the cylindrical buoy. At four

FIGURE 9B

SPHERICAL SEGMENT




| FULL SCALE | |
|---|---|
| A | 3'6" |
| B | 7" |
| C | 1'10" |
| D | 1'7" |
| E | 10" |
| F | 7" |

LIGHTING - 44 Pounds

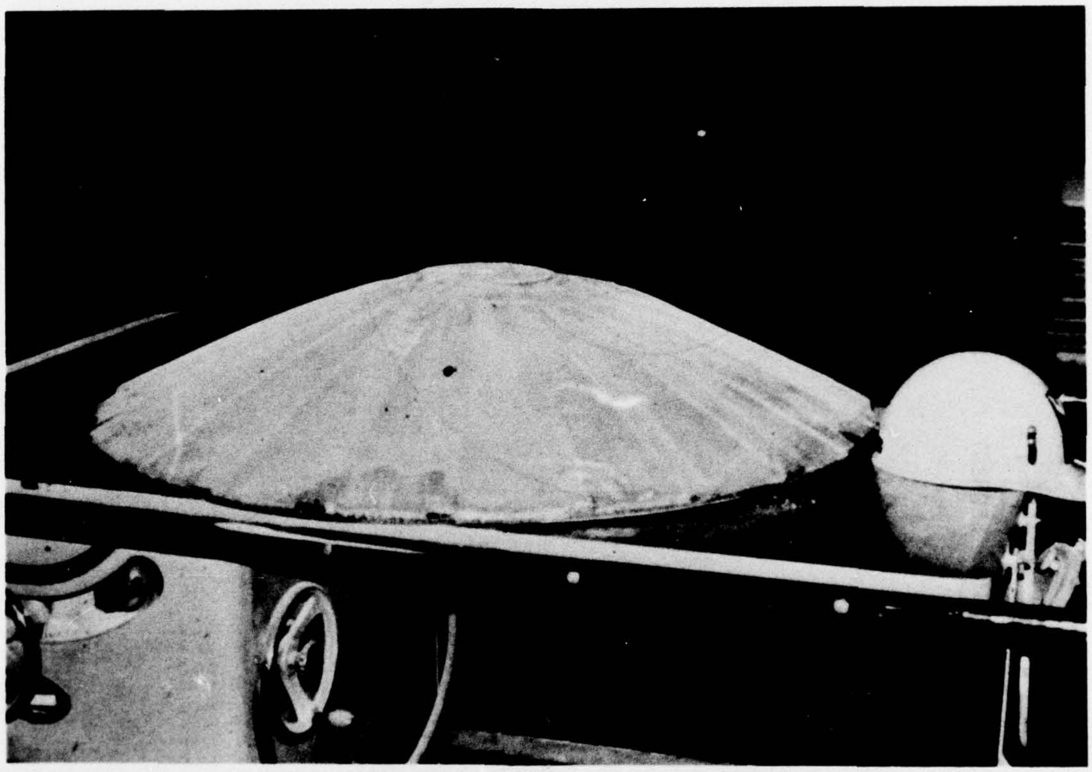
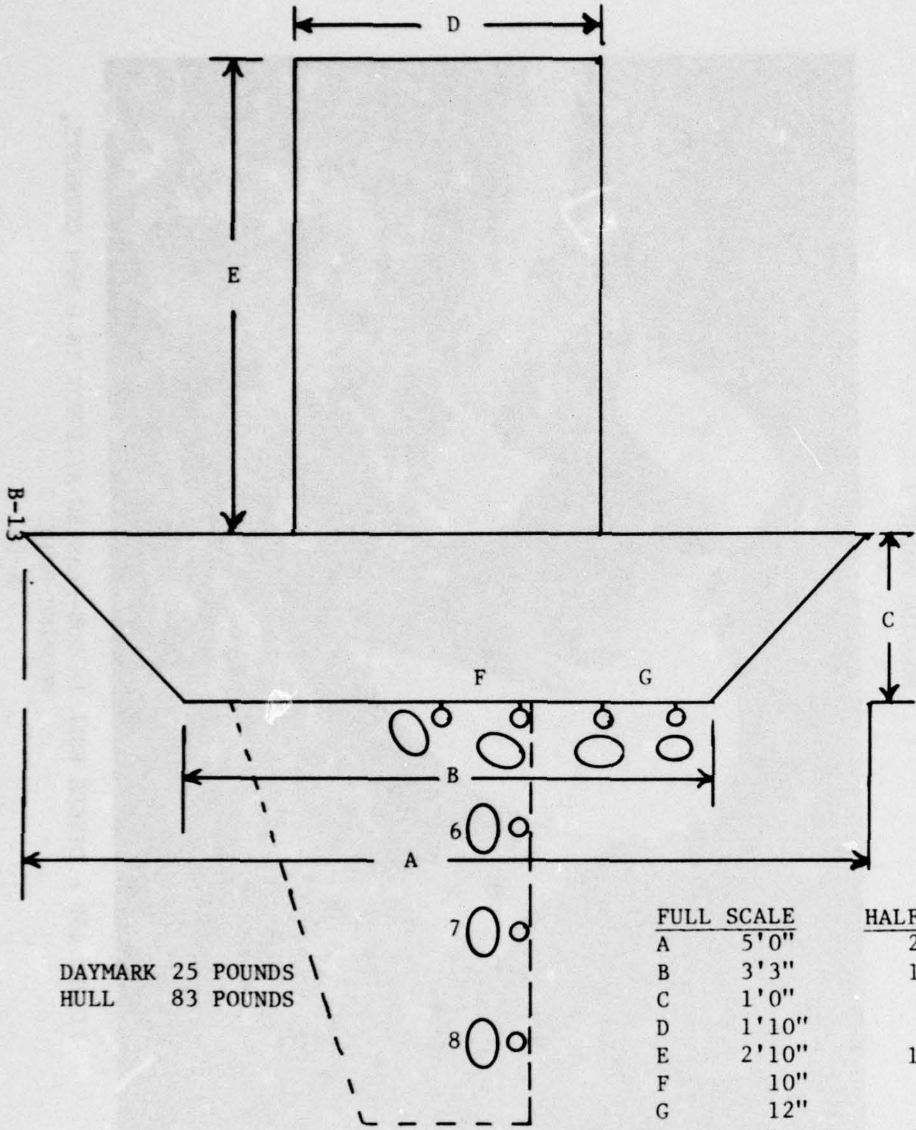
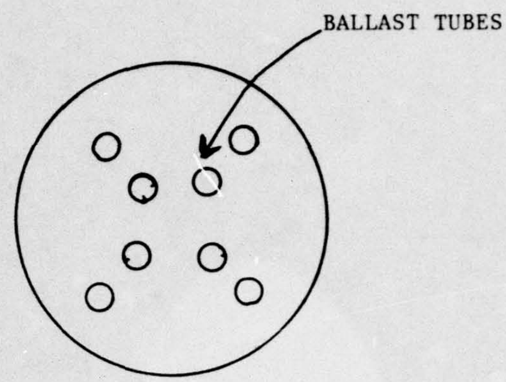


FIGURE 10B - SPHERICAL SEGMENT HULL UNDER CONSTRUCTION

FIGURE 11B
DISCUS HULL




DAYMARK 25 POUNDS
HULL 83 POUNDS

| | FULL SCALE | HALF SCALE |
|---|---|---|
| A | 5'0" | 2'6" |
| B | 3'3" | 1'7-1/2" |
| C | 1'0" | 7" |
| D | 1'10" | 12" |
| E | 2'10" | 1'4" |
| F | 10" | 5" |
| G | 12" | 6" |
| LIGHT WEIGHT | 113 LBS. | 26 LBS. |
| KEEL WEIGHT | 20 LBS. | 2.5 LBS. |

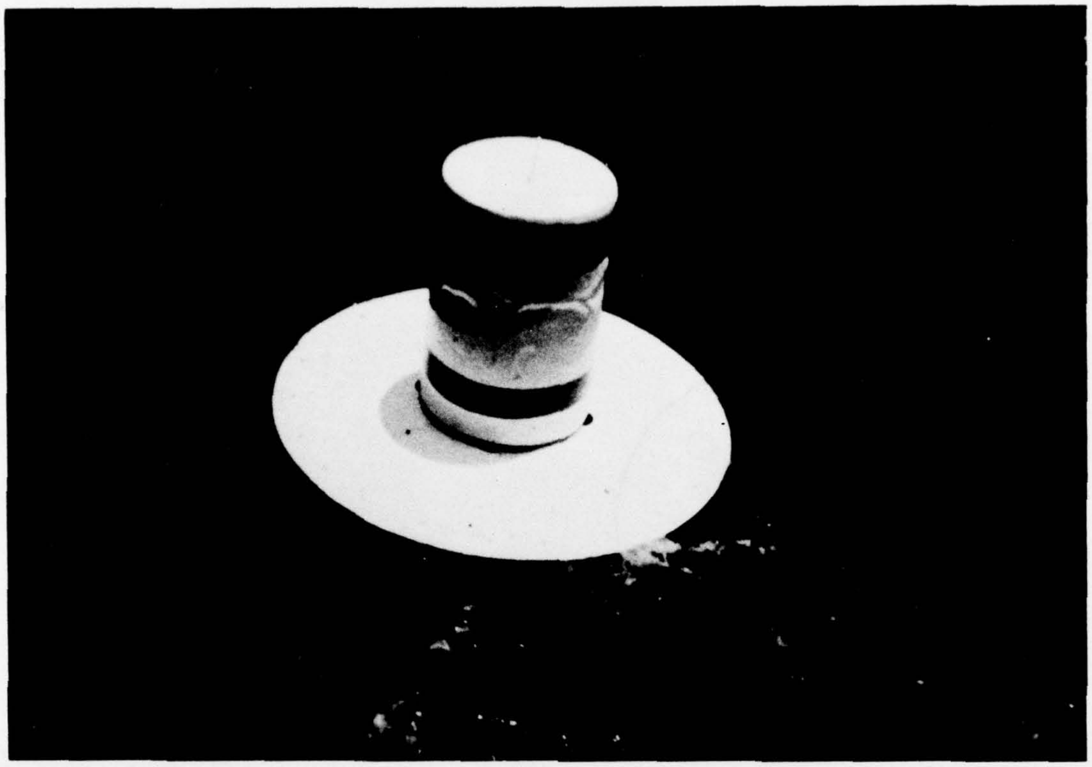


FIGURE 12B - DISCUS HULL IN NON-PLANING ATTITUDE IN 4 MPH CURRENTS, MOORING POINT 1

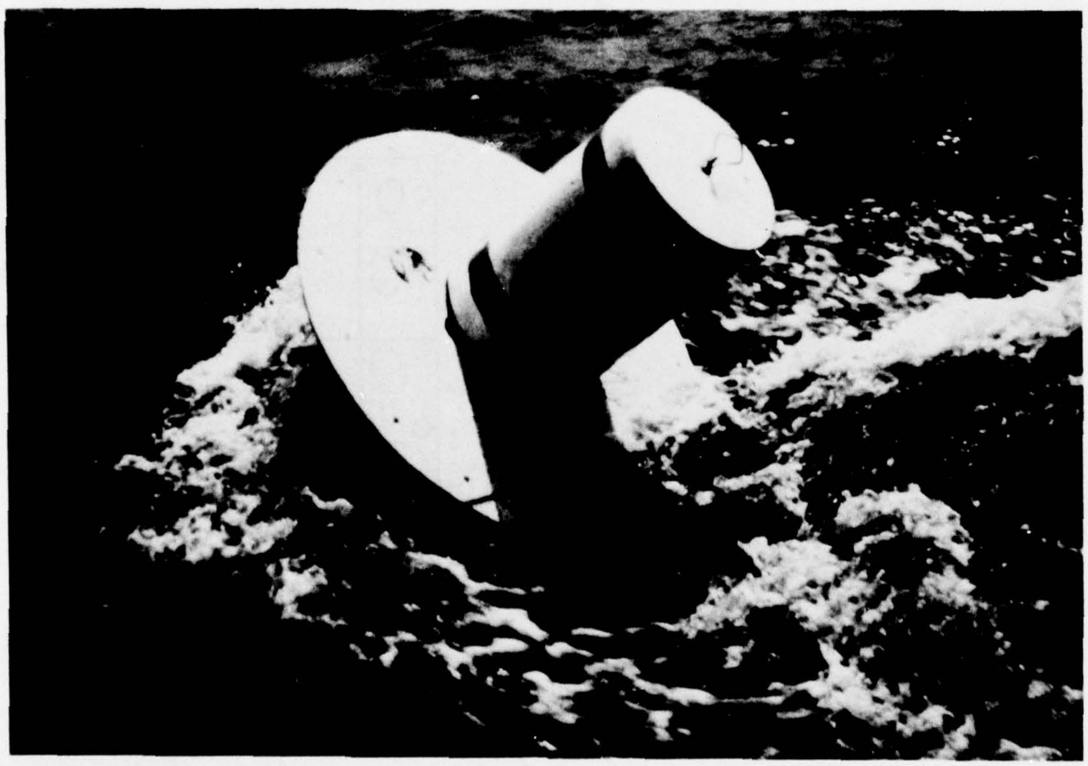


FIGURE 13B - DISCUS HULL IN NON-PLANING ATTITUDE IN 6 MPH CURRENTS, MOORING POINT 1

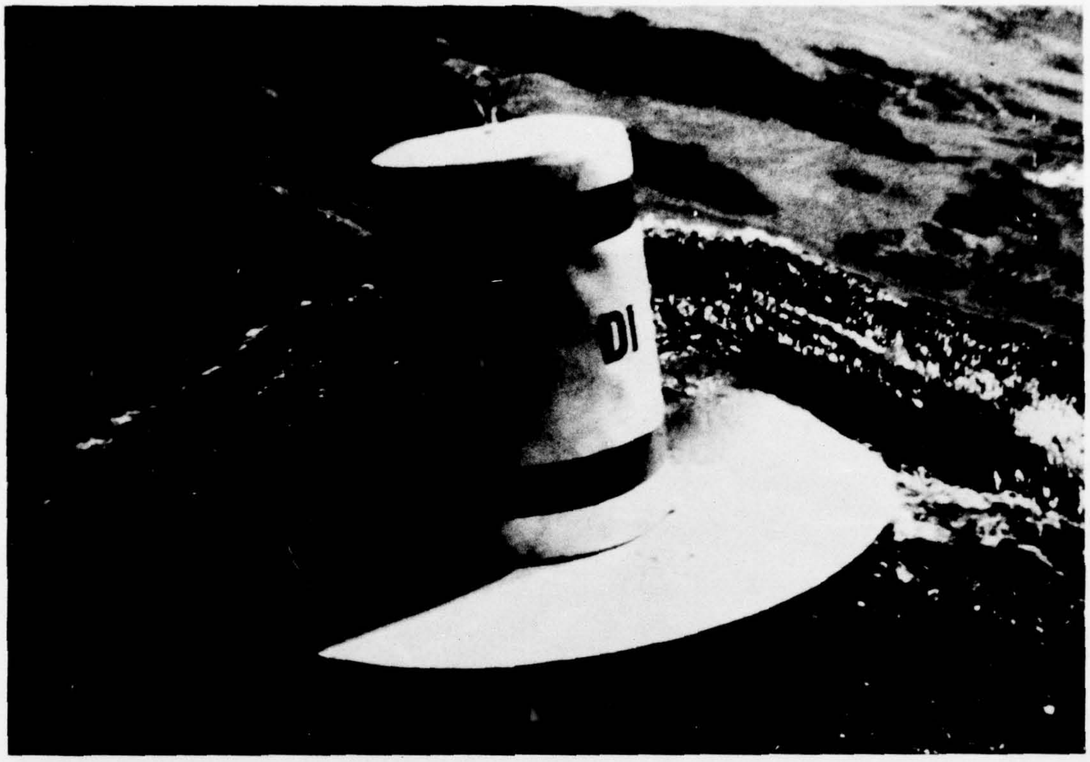



FIGURE 14B - DISCUS HULL AT MOORING POINT 2 IN 4 MPH CURRENT.
IN HIGH VELOCITIES, THIS HULL WILL PLANE.

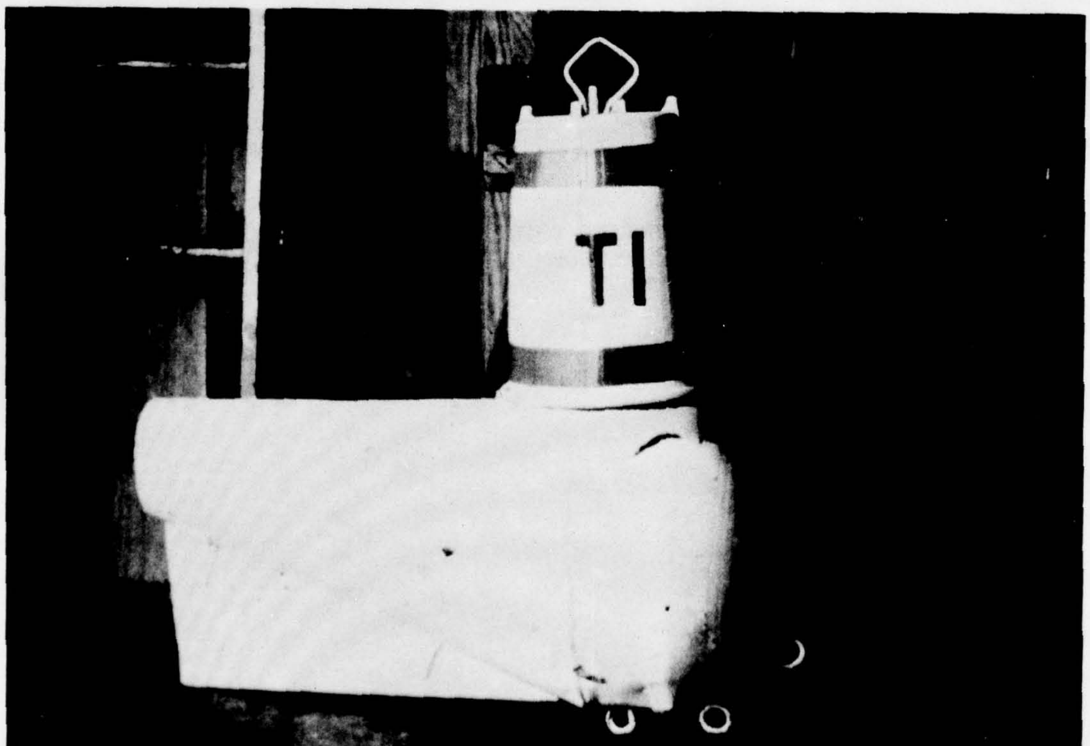



FIGURE 15B - TEARDROP TEST HULL

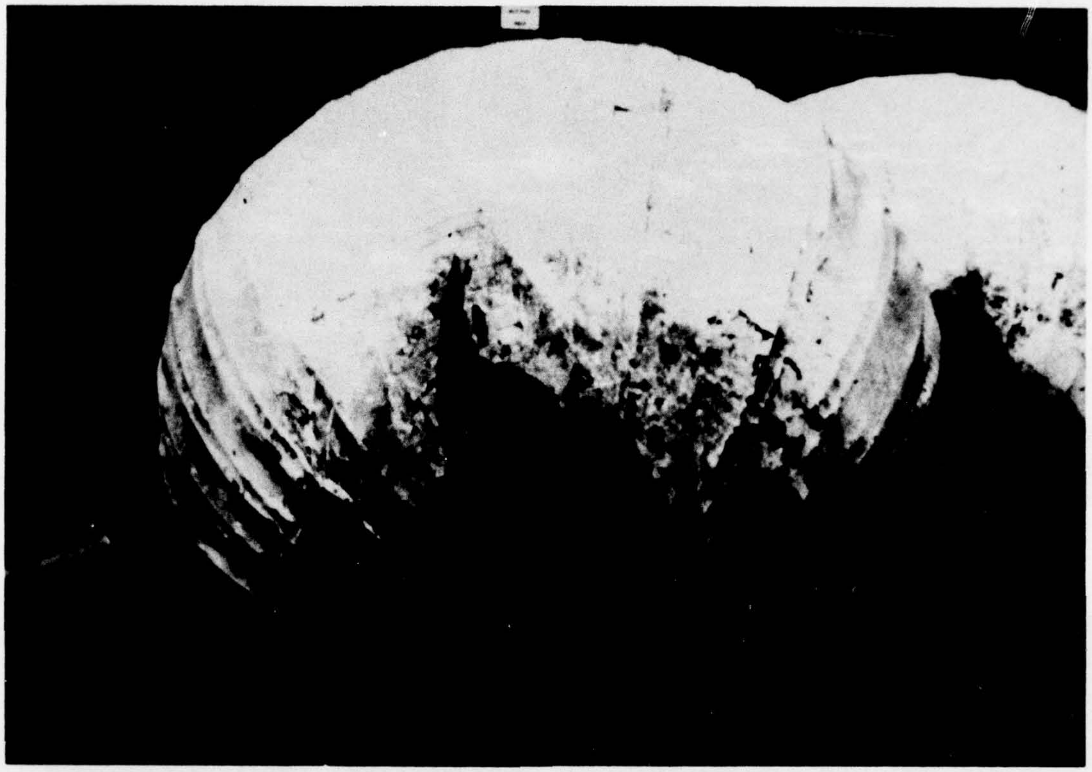


FIGURE 16B - EXAMPLE OF MOORING POINT FAILURE EXPERIENCE DURING INITIAL PERFORMANCE TESTS

miles per hour, the 5th class buoy rode upright, developing a mooring load of 75 pounds. However, as the current approached six miles per hour, the cylindrical hull was pulled under, and a 500-pound mooring load was observed. At eight miles per hour, the buoy, still submerged, developed a mooring load of 750 pounds.

The results of this test only confirmed the inferior performance of the cylindrical shape.

### B.3.7 Mooring Failures

Throughout the tests, the experimental hulls experienced mooring point failures. These failures were caused by extreme mooring load tension developed by swift currents and/or debris accumulation. Figure 16B shows a typical failure, where the entire mooring attachment has been ripped from the hull. These frequent failures attested to the requirement for durable mooring attachment points on fast water test buoys, and, eventually, on the operational fast water buoy.

## B.4 CONCLUSION

The major conclusion based upon the result of the initial performance tests was that the hemispherical and discus buoy hulls remained on the surface in all current conditions, and were thus the two candidates with the highest potential for success (but see Section 3.4, which describes the ultimate rejection of the discus hull).

A significant corollary to this conclusion was that the axisymmetrical hulls performed better than the non-axisymmetric hulls, which eliminated further tests of the barge and boat shape hulls.

# APPENDIX C
# DEVELOPMENT OF A DIGITAL COMPUTER ALGORITHM

## TABLE OF CONTENTS



## LIST OF ILLUSTRATIONS



## LIST OF TABLES

## C.1 ACKNOWLEDGMENT

The digital computer algorithm described in this appendix was developed by Coast Guard Cadet Phillip M. SANDERS. This appendix synopsizes Cadet SANDERS' Academy Scholars Project Report dated 6 May 1974. All figures and tables in this appendix are taken from that report.

## C.2 PURPOSE

The development of a fast water buoy was largely accomplished through an empirical solution approach. This approach, while ultimately successful, was time consuming and required a physical model to test each design modification.

This algorithm was developed to supplement the empirical solution approach. Its purpose was to analyze in a theoretical manner the effects of the forces and conditions which render buoy performance unsatisfactory, and thereby allow researchers to predict, without the need of a physical model, how a given buoy hull form will perform in a Western Rivers environment.

## C.3 METHOD

In the algorithm, a buoy system was analyzed in terms of the forces that continuously act upon the buoy body. Essentially, the model considers a typical fluid dynamic system. Figure 1C shows the forces which were considered to be acting upon a buoy hull:

1. Drag of Form: The buoy hull itself experiences a hydrodynamic drag force in the direction of the current. This force (DRAG) depends upon the coefficient of drag of the buoy (CD), the density of the water (RHO), the surface velocity of the water (VMAX), and the projected area of the buoy normal to the current flow (PROJA). It is expressed in the following equation: DRAG=CD*RHO*VMAX$^2$*PROJA.

2. Debris Drag; Debris which attaches itself to either the mooring or the buoy introduces a hydrodynamic drag force in the direction of the current. This force (DEBRIS) depends upon the coefficient of drag of the debris (CT), as well as the other variables that affect the drag of the buoy hull itself. It is expressed in the equation: DEBRIS=CT*RHO*VMAX$^2$*PROJA.

3. Cable Drag: There is a further hydrodynamic drag force acting on the cable in the direction of the current. This force (DRC) depends upon the coefficient of drag of the cable (CN), the cross sectional area of the cable (A), the density of the water (RHO), and the current velocity acting upon the cable (VELP). It is expressed in the equation: DRC= CN*A*RHO*VELP$^2$.

4. Buoy weight, cable weight: Gravity acts upon the buoy and upon the cable. Gravity acts through the center of gravity of each, perpendicular to the ground. These weights are determined empirically.

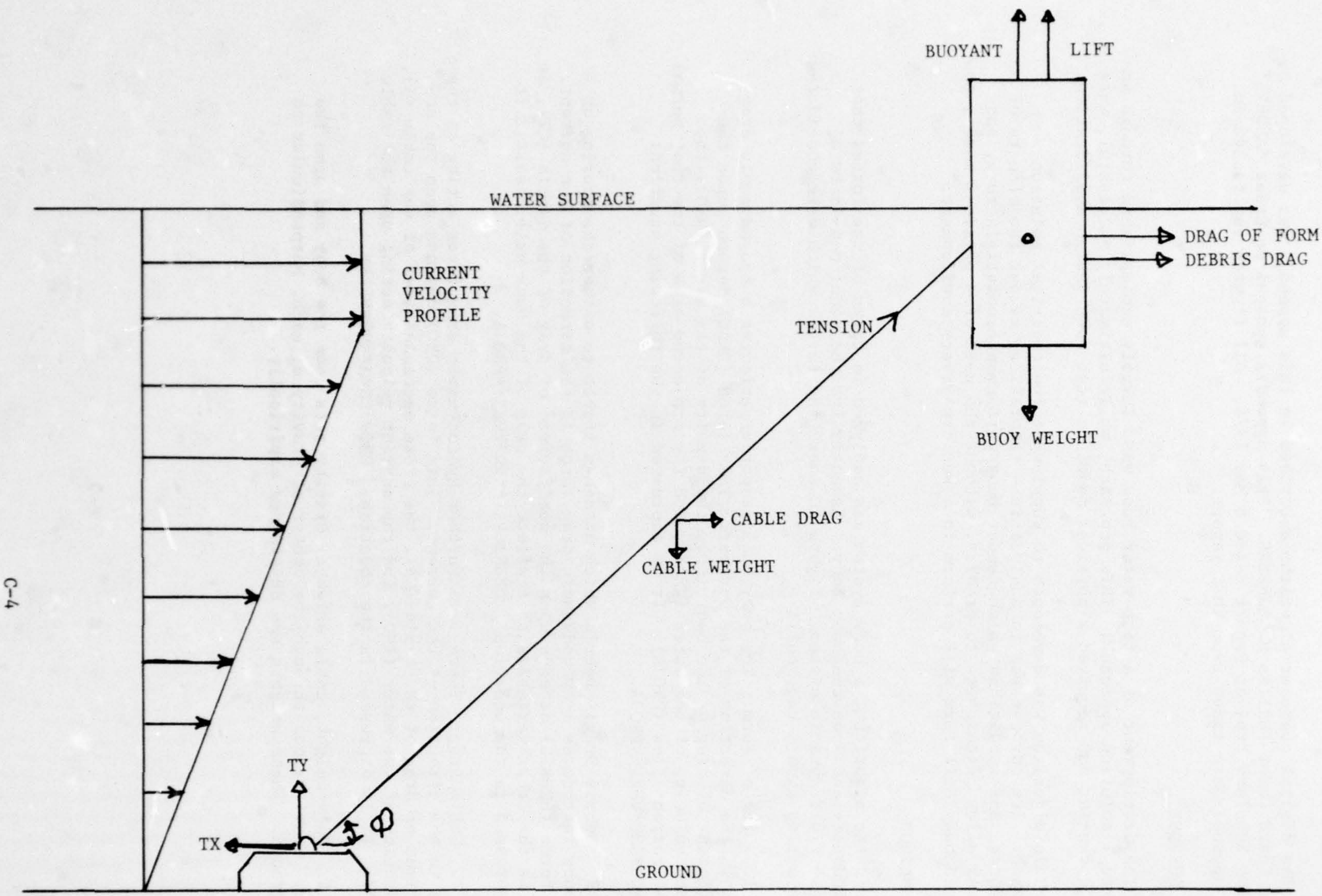



FIGURE 1C - BUOY-FORCE COORDINATE SYSTEM

5. Buoyancy: The submerged underwater volume of the buoy causes a resultant buoyant force and acts opposite to the force of gravity, through the center of buoyancy. This buoyant force (BUOY) is determined by multiplying the submerged volume (in cubic feet) of the buoy times a constant (62.4 pounds per cubic feet).

6. TX, TY: The sinker feels a force TX and TY in the horizontal and vertical direction due to the weight of the sinker, frictional contact with the bottom, and the forces from the buoy/cable system. For the purposes of the model, the sinker is assumed to be fixed to the bottom, thus the major consideration is the tension in the cable, which is discussed below.

7. Tension: The mooring cable experiences a tension force, which depends upon the total drag of the system (TDRAG=DRAG + DEBRIS + DRC) plus the net vertical force (TBUOY=BUOY+Lift Force (LF, see below) - (Weight of Buoy (BWT) + Weight of Cable (XL*W). The tension in the cable (T) is expressed by the following equation: $T = \sqrt{TDRAG^2+TBUOY^2}$.

8. Lift: The final force considered is a hydrodynamic lift that is created in some hulls, which is assumed to act in the direction of the buoyant force. This lift force (LF) of lift of the buoy (CL), the density of the water, the velocity of the current, and the projected area of the buoy normal to the current flow. It is expressed in the equation: $LF=CL*RHO*VMAX^2*PROJA$.

Using the above mentioned forces, the model views the buoy/cable system as being in static equilibrium. Thus:

a. The vector sum of all forces acting on the system must equal zero, and

b. The sum of the moments about any point must equal zero. The model considers this point to be the sinker, which is assumed to be firmly fixed to the river bottom.

Thus, the solution is based upon the following three equations (see Table 1C for a listing of all the variables):

(1) T COS Ø (where Ø is the angle the buoy cable makes with the bottom) = DRAG + DEBRIS.

(2) T SIN Ø = BUOY + LF - BWT - (W*XL)

(3) XMDRAG+XMDEBR+XMDRC+XMW+XMBWT-XMBUOY-XMLIFT=0

## C.4 ASSUMPTIONS

In order to simplify calculations, these assumptions were made:

1. That for current velocities about four miles per hour (those of primary interest), the cable is without catenary and is approximated by a straight line.

2. That the effect of wind is negligible.

TABLE 1C

HULL MODEL PROGRAM VARIABLES

| | |
|---|---|
| A | Cross sectional area of cable |
| BUOY | Buoyant force due to submerged volume of buoy |
| BWT | Weight of buoy |
| CD | Coefficient of drag of buoy |
| CL | Coefficient of lift of buoy |
| CN | Normal drag coefficient of cable |
| CPHI | Cosine PHI |
| CT | Coefficient of drag of debris |
| D | Tolerance in root finding method |
| DA | Projected area of daymark normal to current flow in square feet |
| DAY | Projected area of daymark normal to line of sight in square feet |
| DAYI | Non-buoyant daymark area above buoy body (i.e., radar reflector) |
| DEBRIS | Drag force due to debris in pounds |
| DEPTH | Depth of water in feet |
| DIA | Cable diameter in feet |
| DRC | Drag force due to cable in pounds |
| DRAG | Drag force due to buoy in pounds |
| ERR | Sum of moments about point of mooring at bottom |
| ERRI | Sum of moments about point of mooring at bottom |
| GAMMA | Angle that the conical section of buoy cross section makes with a line perpendicular to base |
| H | Draft of buoy in feet |
| HC | Total height of conical section |
| HD | Thickness of disc section |
| L | Loop index for S (L) |
| LF | Lift force (dynamic) of the buoy |
| HI | Twice radius minus draft on spherical buoy |
| HTOT | Total height of buoy body in feet |
| I | Loop index counting number of different data groups |
| K | Counter in root finding routine |
| M | Midpoint of binary chop |
| N | Number of buoys tested |
| PHI | Angle cable makes with bottom in radians |
| PHII | PHI in degrees |
| PI | Constant PI |
| PROJA | Projected area of buoy normal to current flow in square feet |
| RESB | Reserve buoyance of buoy in pounds |
| RHO | Water density divided by two (2) in pounds per cubic feet |
| RI | Radius of portion of a conic section in feet |

TABLE 1C (cont.)

| | |
|---|---|
| S (I) | Alphanumeric storage for buoy type |
| SCOPE | Scope of mooring; length/depth |
| SHAPE | Indicates buoy type |
| SPHI | Sine of Phi |
| T | Tension due to forces acting only on buoy in pounds |
| THETA | Angle T makes with bottom in radians |
| TX | Horizontal tension at sinker in pounds |
| TY | Vertical tension at sinker in pounds |
| TBUOY | Total vertical forces due to buoy in cable in pounds |
| TDRAG | Total horizontal forces due to buoy on cable in pounds |
| U | Upper bound for draft in feet |
| V | Lower bound for draft in feet |
| VELIN | Exponent of velocity at a point calculation |
| VELP | Velocity at a point along depth in feet per second |
| VMAX | Surface velocity - feet per second |
| VKTS | Surface velocity - knots |
| W | Weight per unit length of cable in water in pounds per foot |
| XKT | Counter for debris accumulations |
| XLIFT | Force on buoy due to hydrodynamic lift pounds |
| XL | Length of cable in feet |
| XMBWT | Moment due to BWT |
| XMBUOY | Moment due to BUOY |
| XMDEBR | Moment due to debris |
| XMDRC | Moment due to cable drag |
| XMLIFT | Moment due to lift |
| XMW | Moment due to cable weight |
| Y | Argument of angle in spherical buoy calculation |

3. That the current profile assumes a straight line approximation, but it is of uniform velocity at the buoy.

4. That all cable debris slides up the cable to the top of the mooring, and that the remainder of the debris is surface debris.

5. That the buoy maintains a uniform orientation upright in the stream under all velocities and debris conditions.

6. That the analysis is limited to a two dimensional analysis of coplanar forces with motion only in one plane.

7. That the sinker is fixed to the bottom.

## C.5 APPROXIMATIONS

The following approximations were used in the model:

1. The velocity of the current acting over the length of the buoy is equal to the surface velocity.

2. The current profile is linear or quadratic, depending upon VELIN (exponent of velocity).

3. Drag on the cable is considered only in the direction of current flow, and not along the cable.

4. The coefficients of drag and lift were approximated from authoritative sources.

## C.6 THE PROGRAM

The program itself is set up as a series of subprograms, each solving a different part of the problem. Figure 2C shows the logic of the main program; 3C, the logic of the subroutine "tension"; 4C, the logic of the subroutine "root"; and 5C, the logic of the subroutine "error."

The program is designed to input shape and weight of the buoy, depth of water, length and type of mooring, starting surface velocity, velocity profile information, and initial debris accumulation.

Given the above conditions, boundary conditions are imposed on the buoy draft. Using the upper and lower bounds as drafts, the forces acting at that draft are calculated, and the sum of the moments then calculated. After the upper and lower bounds for the sum of the moments are calculated, and interval halving root finding method is used to determine the draft by changing the draft until the sum of the moments is equal to zero.

Tension in the cable is calculated at the resulting draft for the buoy/cable system. The forces acting in both the horizontal and vertical direction at the sinker (TX, TY) are calculated. Reserve buoyancy and available daymark area are then calculated, as are the scope and buoy excursion.

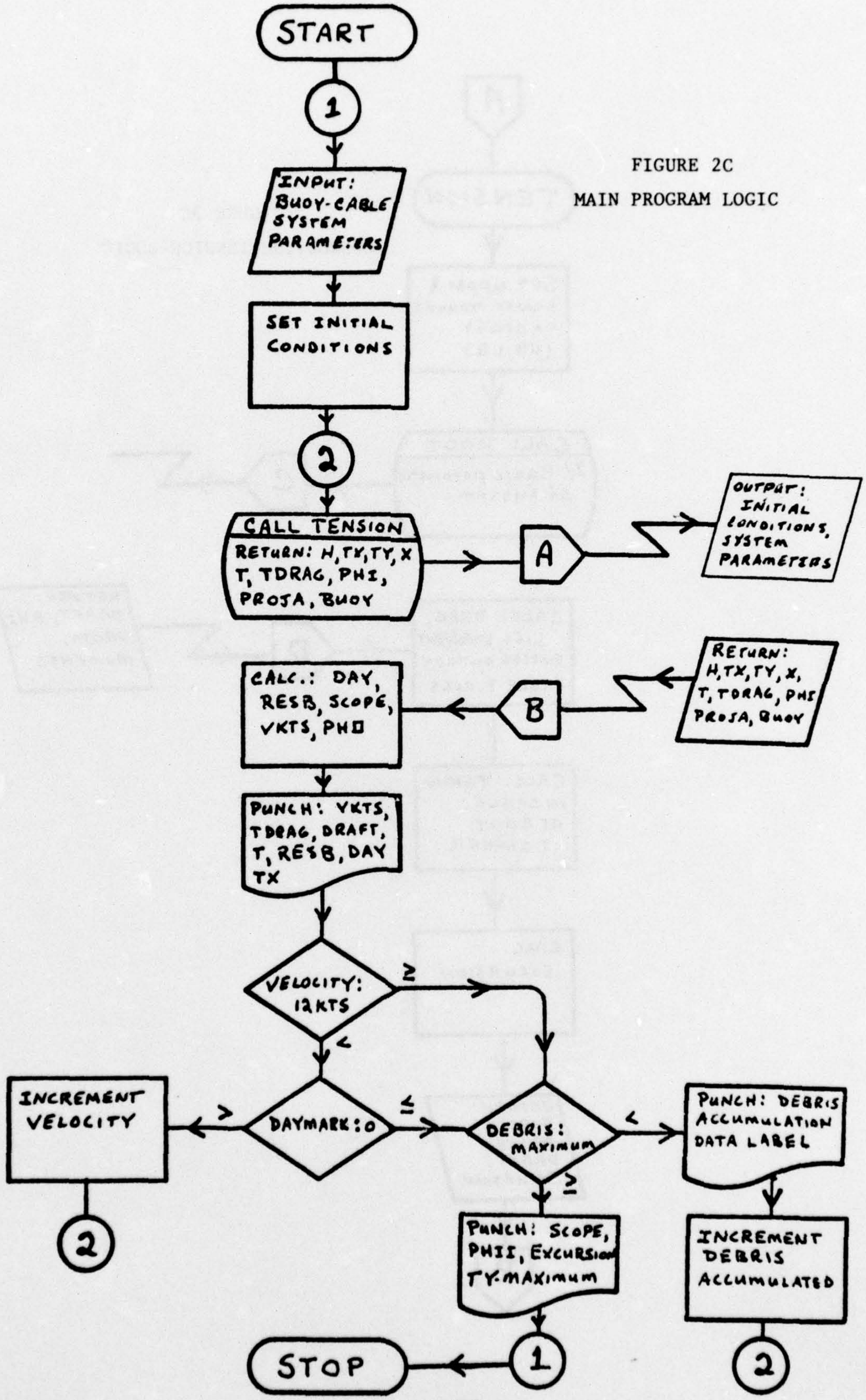



FIGURE 2C

MAIN PROGRAM LOGIC

FIGURE 3C

SUBROUTINE TENSION-LOGIC

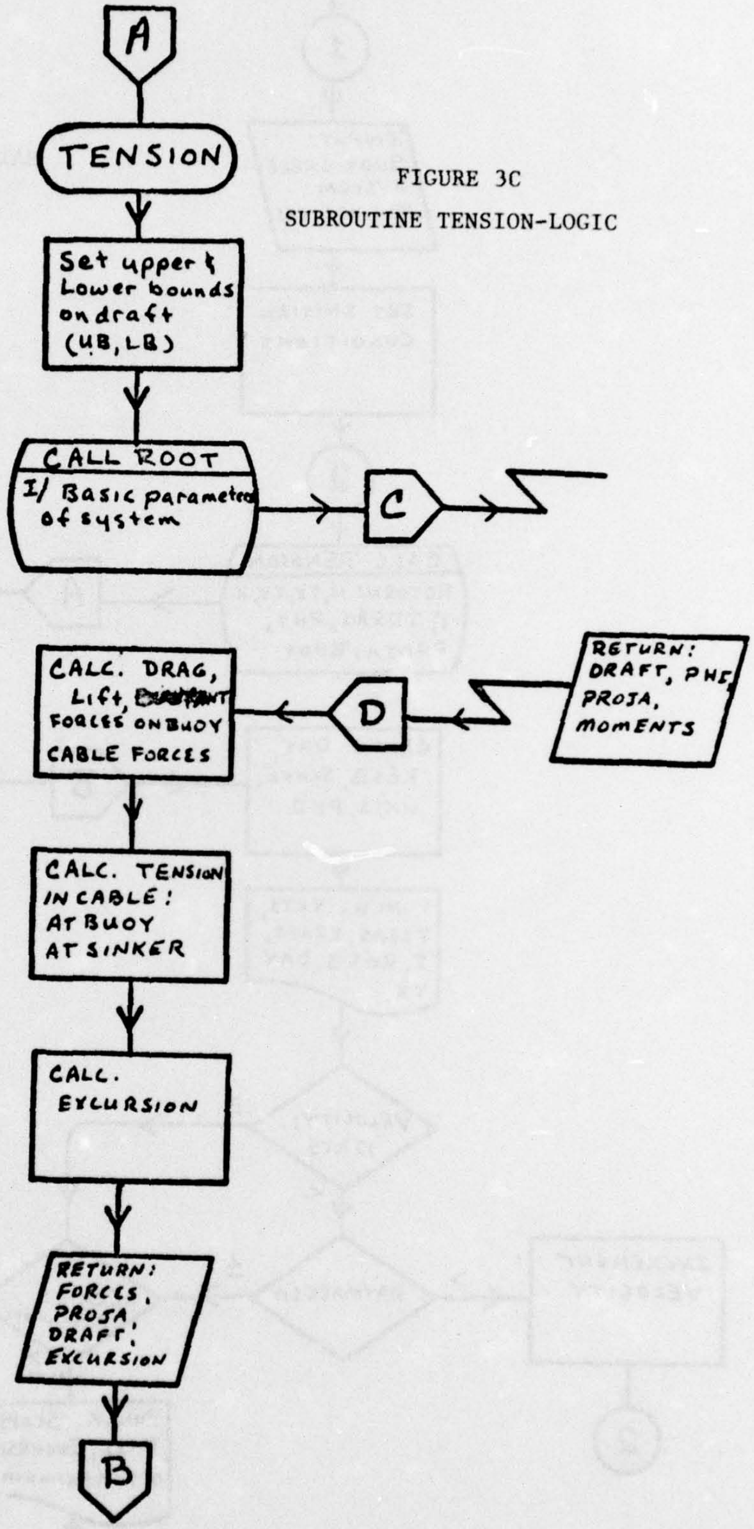
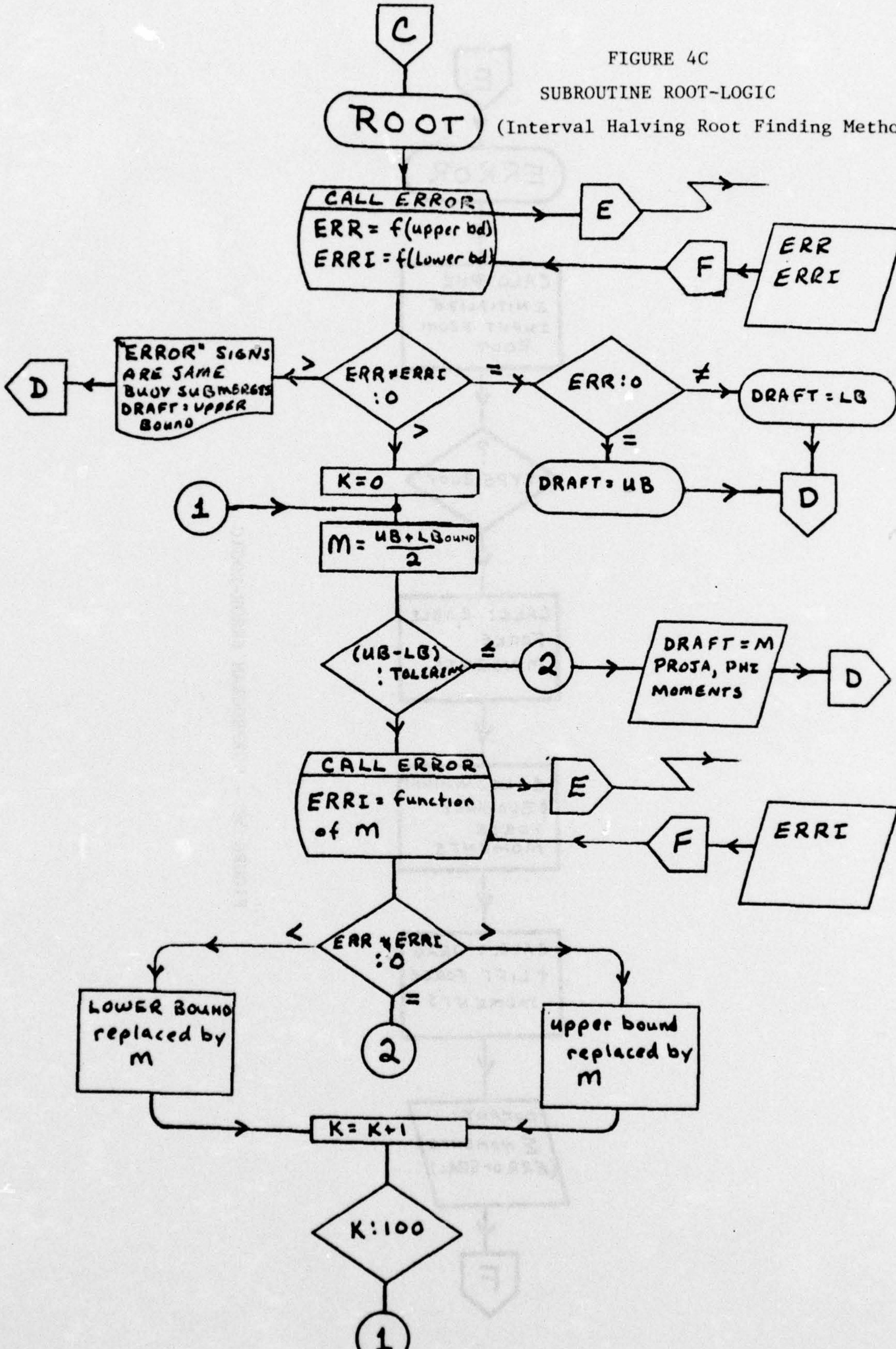


FIGURE 4C

SUBROUTINE ROOT-LOGIC

(Interval Halving Root Finding Method)




C-11

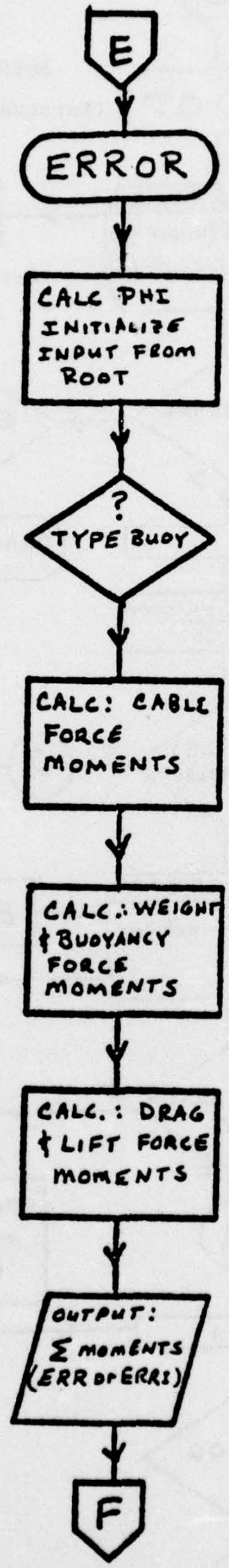



FIGURE 5C - SUBPROGRAM ERROR-LOGIC

The final outputs are: velocity, total drag, draft, tension, reserve buoyancy, daymark area, anchor tension, excursion, and scope. Decisions are made to determine whether the buoy has submerged, or whether the maximum velocity to be considered has been reached. Numerical iteration procedure of velocity is carried on until one of the conditions is met. Once either of the above conditions is met, velocity is reset to zero. Debris accumulation is then incremented and calculation begins again until either the buoy submerges or maximum velocity is reached. The debris incrementation is carried out until the maximum accumulation to be modeled is reached. Then the program inputs the next hull form conditions.

## C.7 CONCLUSION

Using the computer model, the following theoretical predictions are possible:

1. For a given amount of debris accumulation and a given scope, the model predicts the velocity at which the buoy submerges, as well as the range of velocities at which the daymark area is sufficient to provide adequate service to the mariner.

2. Cross plots of the curves of buoy performance at different scopes can be made to give the optimum scope information for each buoy.

3. Any further plots can be made by changing a format statement in the plot routine or by plotting the desired information by hand.

4. Mooring tension is provided as a function of current velocity. From this, the expected cable tension can be compared with desired safety factors, and in this way the adequacy of the cable can be determined.

Thus the model provides all the information needed to determine station-keeping ability of a given hull over a range of river conditions.

## APPENDIX D
## PISCATAQUA RIVER DEPLOYMENT TEST

### TABLE OF CONTENTS



### LIST OF ILLUSTRATIONS



### LIST OF TABLES

## D.1 OBJECTIVES

For approximately three weeks, an array of test buoys was established in the tidal estuary of the Piscataqua River, off Dover Point, New Hampshire. There were two objectives of this test:

1. To observe buoy performances under identical river conditions, and

2. To test the validity of the computer model described in Section 4.1 and Appendix C of this report.

## D.2 METHODOLOGY

The Piscataqua River site was selected because the biurnal ebb and flood of the tide produced a range of currents between two and six knots in close, predictable succession. In addition, during the test, weather influenced river conditions with 35 knot winds creating five-foot waves contrasted with days of near calm.

Included within the array of buoys established were standard 4th and 6th class (one with dynamic lifting fins) buoys, 3-foot and 4-foot hemispherical test buoys, a 3-foot diameter sphere, and a 4-foot and 5-foot diameter discus hull. Mooring load cells were attached in line with the moorings and a current meter was used to measure the current velocity alongside each buoy. A visual record was made with slides and movies.

## D.3 RESULTS

### D.3.1 Buoy Performance

Buoy performance was observed at three different scopes - 1.2, 3.3, and 5.2.

At 1.2, the following results were observed:

1. Discus Hulls: In a current of five knots, both 4-foot and 5-foot diameter discus hulls refused to plane. Once a load cell was attached, they both dove, and it was not possible to improve their performance.

2. Standard Buoys: Both 6th class buoys were tested at this scope, and they were completely submerged, visible during periods at or near slack water. The buoys also dragged their 2000-pound concrete sinker moorings.

3. Hemispherical Hulls: Both bottom moored hemispheres (3-foot and 4-foot diameter) rode well, but displayed a 45° aft trim (an expected result, as the Arkansas River tests, Section 5.3.1 of this report, showed). The side moored hemispheres did not exhibit this trim, but rode upright. The spherical hull also rode well at this scope. None of the buoys shifted their moorings.

At a scope of 3.3, the following results were observed:

1. Standard Buoys: At this scope with a 3.5 to 4.3 knot current, the regular 6th class buoy remained submerged, but occasionally the extreme top of the buoy would bob above the water's surface. A 6th class buoy modified

with a dynamic lifting fin (see Appendix A.2.3 concerning this design) displayed similar performance, although it did rise further above the surface of the water when it occasionally broke the surface. The 4th class buoy remained on the surface in currents below four knots; however, the buoy leaned over on its side at an angle of as much as 60°. As the current velocities increased, more of the buoy body would become submerged, with maximum submergence of 60 percent of the buoy body observed. Both 6th and 4th class buoys shifted their moorings.

2. Hemispherical Hulls: All hemishperical/spherical hulls performed well at this scope. Again, the bottom moored hemisphere displayed considerable trim aft, whereas the side moored hemispheres did not. No shift of moorings was observed.

At a scope of 5.2, the following results were observed:

1. Standard Buoys: In currents under four knots, 95 percent of the conventional 6th class buoy remained submerged. The 6th class buoy modified with the lifting fin oscillated back and forth across the river, diving as it reached its farthest point of arc, at which point 80 percent of the buoy would be submerged. As at a scope of 3.3, the 4th class buoy leaned on its side at a 5.2 scope, and did oscillate occasionally (as it did at a scope of 3.3).

2. Hemispherical Hulls: All buoys rode well, with the same performance characteristics described above.

### D.3.2 Computer Model Verification

Tables 2D through 7D are plots of the maximum/minimum range of the dynamic load observed during the test for each buoy type involved. Overall, the computer model tended to underestimate the actual mooring load. The model was a steady state simulation that could not estimate the effect of wind and waves upon mooring tension. The test proved that mooring tension is actually a time varying range of mooring tensions, which varies by two to three times the minimum observed tension, depending upon the effects of wind and waves.

## D.4 CONCLUSION

### D.4.1 Buoy Performance

A spherical section buoy (hemispherical or a sphere) is better suited to a swift water condition than the conventional cylindrical buoy. However, with a hemispherical hull topped by a daymark, a side mooring is required to insure that the daymark remains upright and visible.

Discus or other similar planing hull designs are not suited to fast water conditions, because they do not consistently plane and are unstable.

### D.4.2 Computer Model Accuracy

The model is inaccurate quantitatively. However, the model does accurately predict comparative performance of different buoy hulls in regard to daymark area, resistance to debris accumulation, and comparative (qualitative) mooring loads observed.

TABLE 1D

EXPLANATION OF SYMBOLS FOR TENSION VS. CURRENT PLOTS

X = Ebb tide, 3.3 scope, Predicted current

• = Flood tide, 3.3 scope, Predicted current

$\boxed{X}$ = Ebb tide, 5.2 scope, Predicted current

$\boxed{\bullet}$ = Flood tide, 5.2 scope, Predicted current

$\triangle$X = Ebb tide, 3.3 scope, Measured current

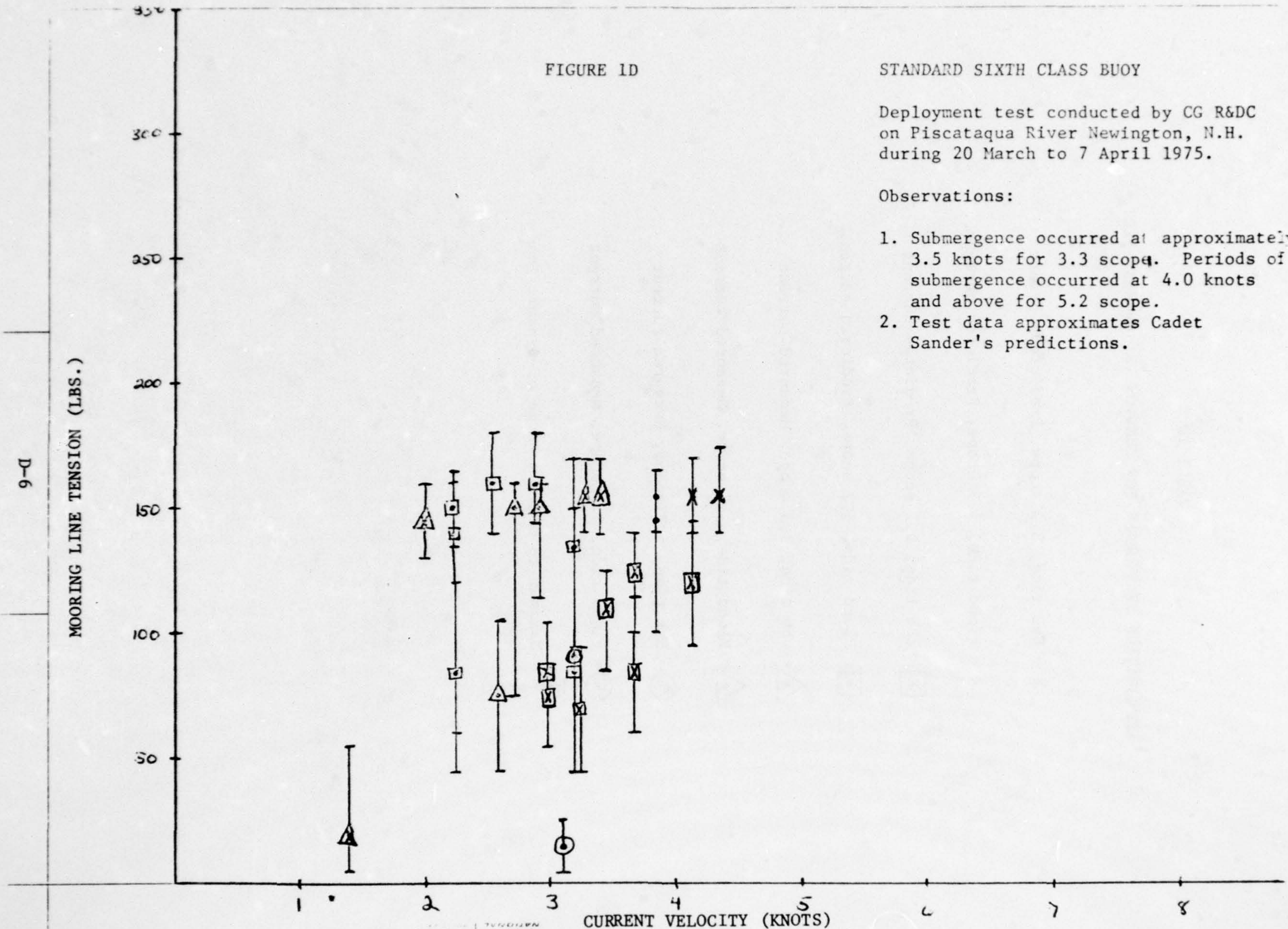
$\triangle$• = Flood tide, 3.3 scope, Measured current

(X) = Ebb tide, 5.2 scope, Measured current

(•) = Flood tide, 5.2 scope, Measured current

I = Maximum to minimum range of dynamic load

FIGURE 1D




STANDARD SIXTH CLASS BUOY

Deployment test conducted by CG R&DC on Piscataqua River Newington, N.H. during 20 March to 7 April 1975.

Observations:

1. Submergence occurred at approximately 3.5 knots for 3.3 scope. Periods of submergence occurred at 4.0 knots and above for 5.2 scope.
2. Test data approximates Cadet Sander's predictions.

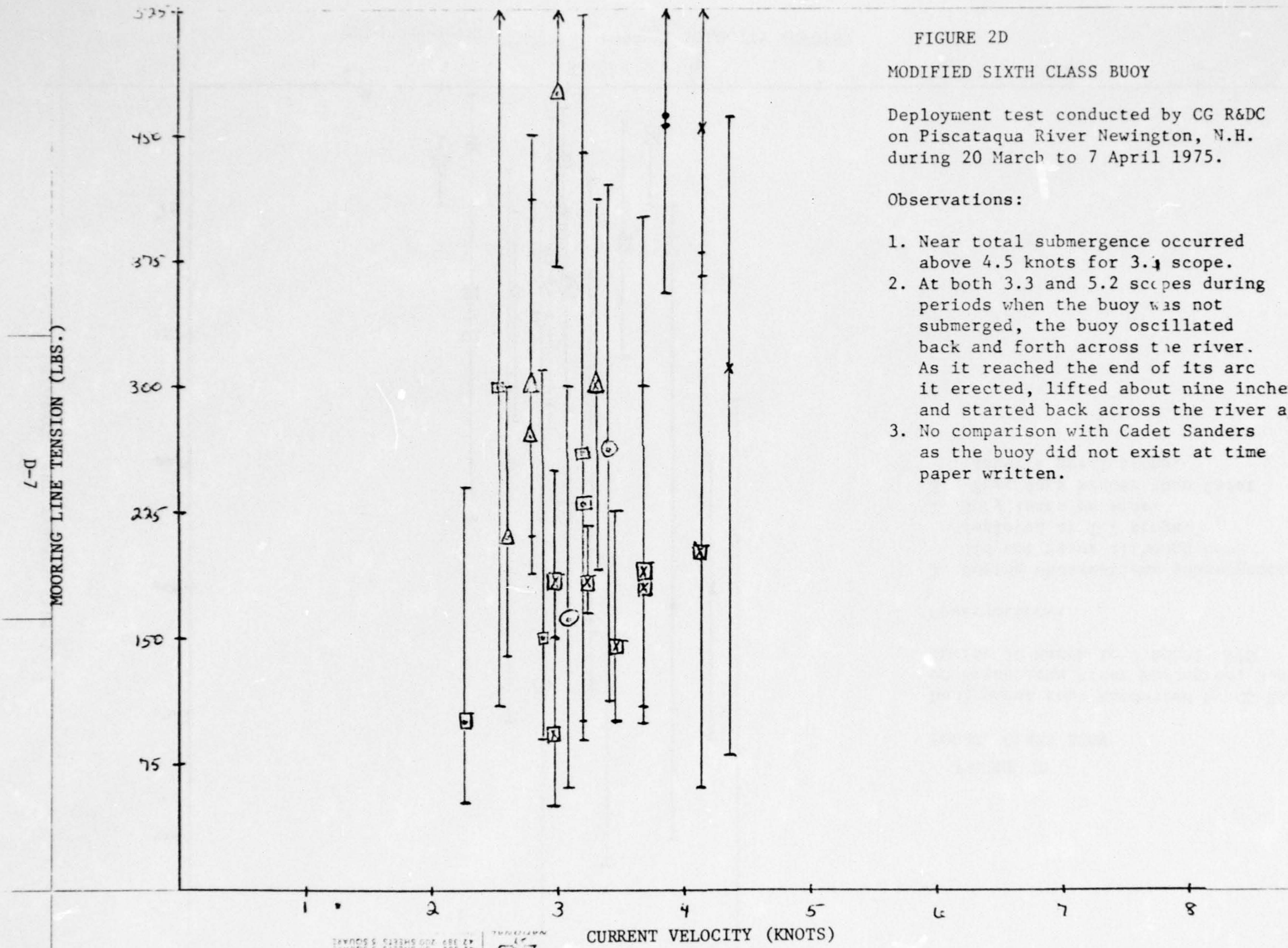



FIGURE 2D

MODIFIED SIXTH CLASS BUOY

Deployment test conducted by CG R&DC on Piscataqua River Newington, N.H. during 20 March to 7 April 1975.

Observations:

1. Near total submergence occurred above 4.5 knots for 3.1 scope.
2. At both 3.3 and 5.2 scopes during periods when the buoy was not submerged, the buoy oscillated back and forth across the river. As it reached the end of its arc it erected, lifted about nine inches, and started back across the river ag
3. No comparison with Cadet Sanders as the buoy did not exist at time paper written.

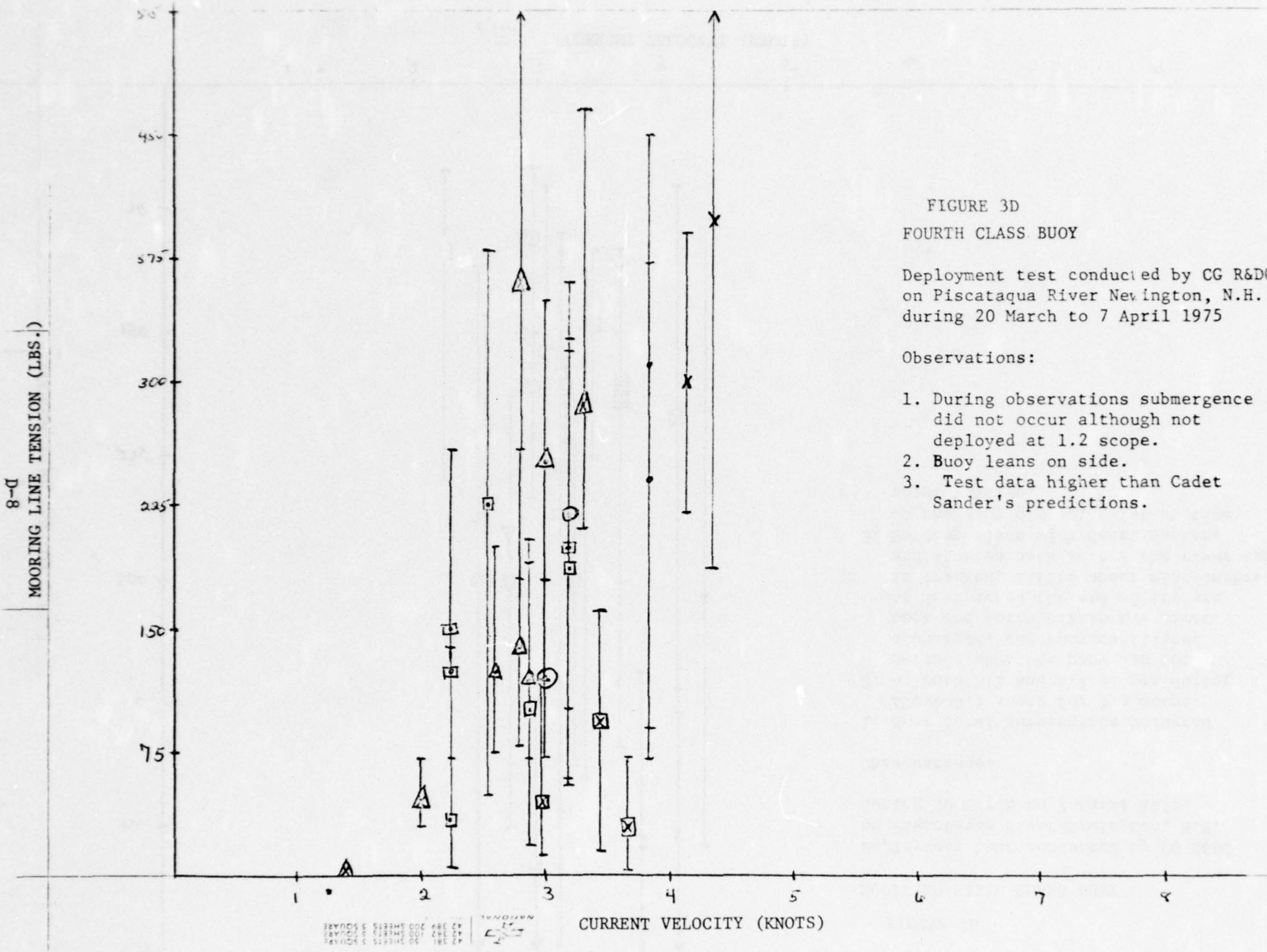



FIGURE 3D

FOURTH CLASS BUOY

Deployment test conducted by CG R&DC on Piscataqua River Newington, N.H. during 20 March to 7 April 1975

Observations:

1. During observations submergence did not occur although not deployed at 1.2 scope.
2. Buoy leans on side.
3. Test data higher than Cadet Sander's predictions.

FIGURE 4D

THREE FOOT DIAMETER HEMISPHERICAL BUOY

Deployment test conducted by CG R&DC
on Piscataqua River Newington, N.H.
during 20 March to 7 April 1975.

Observations:

1. During observations submergence did not occur.
2. Test data higher than Cadet Sander's predictions.

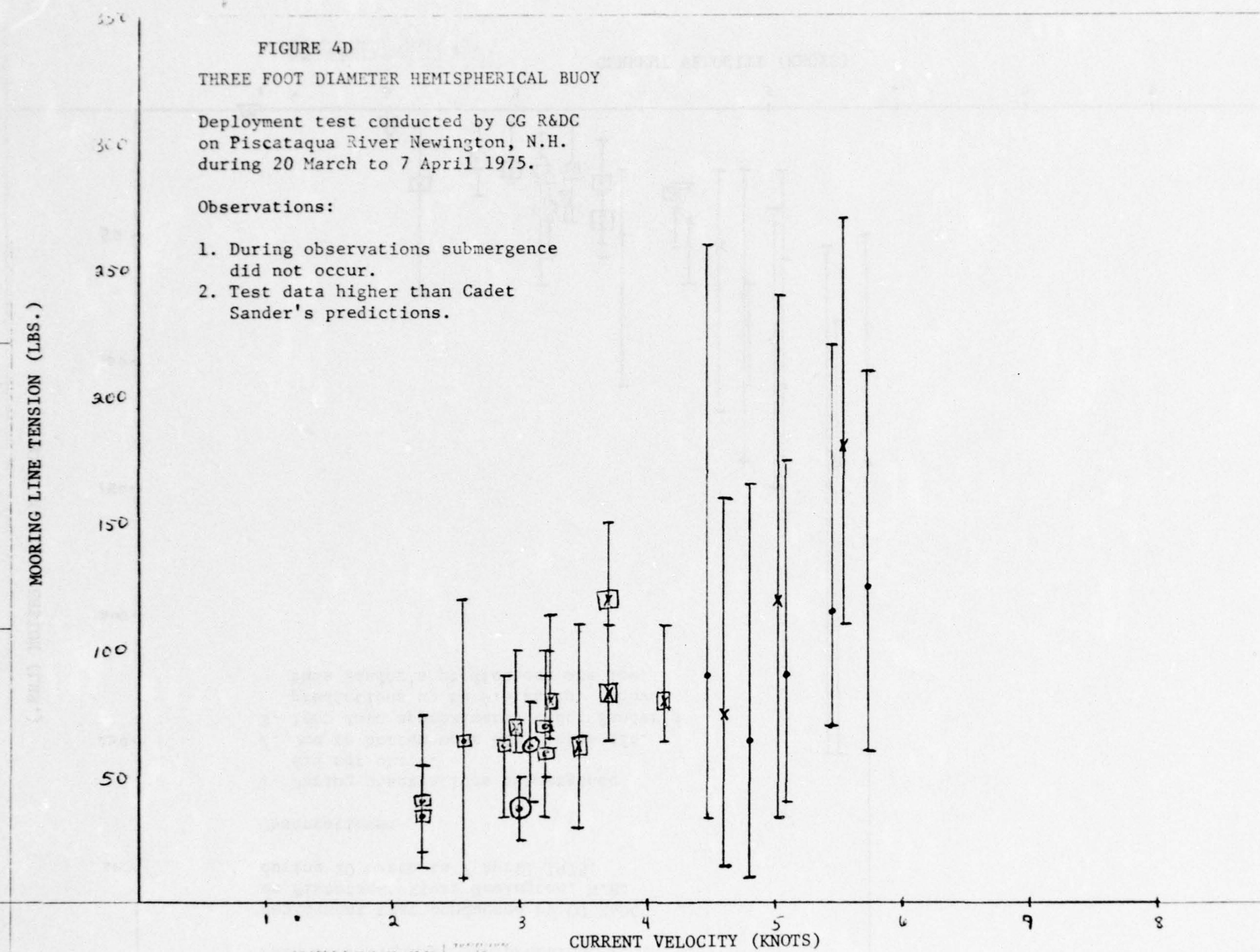


FIGURE 5D
FOUR FOOT DIAMETER HEMISPHERICAL BUOY

Deployment test conducted by CG R&DC
on Piscataqua River Newington, N.H.
during 20 March to 7 April 1975.

Observations:

1. During observations submergence did not occur.
2. Due to bottom moor buoy trims aft.
3. Test data approximates Cadet Sander's predictions up to 4.5 knots. Above this Sander's predictions are low.

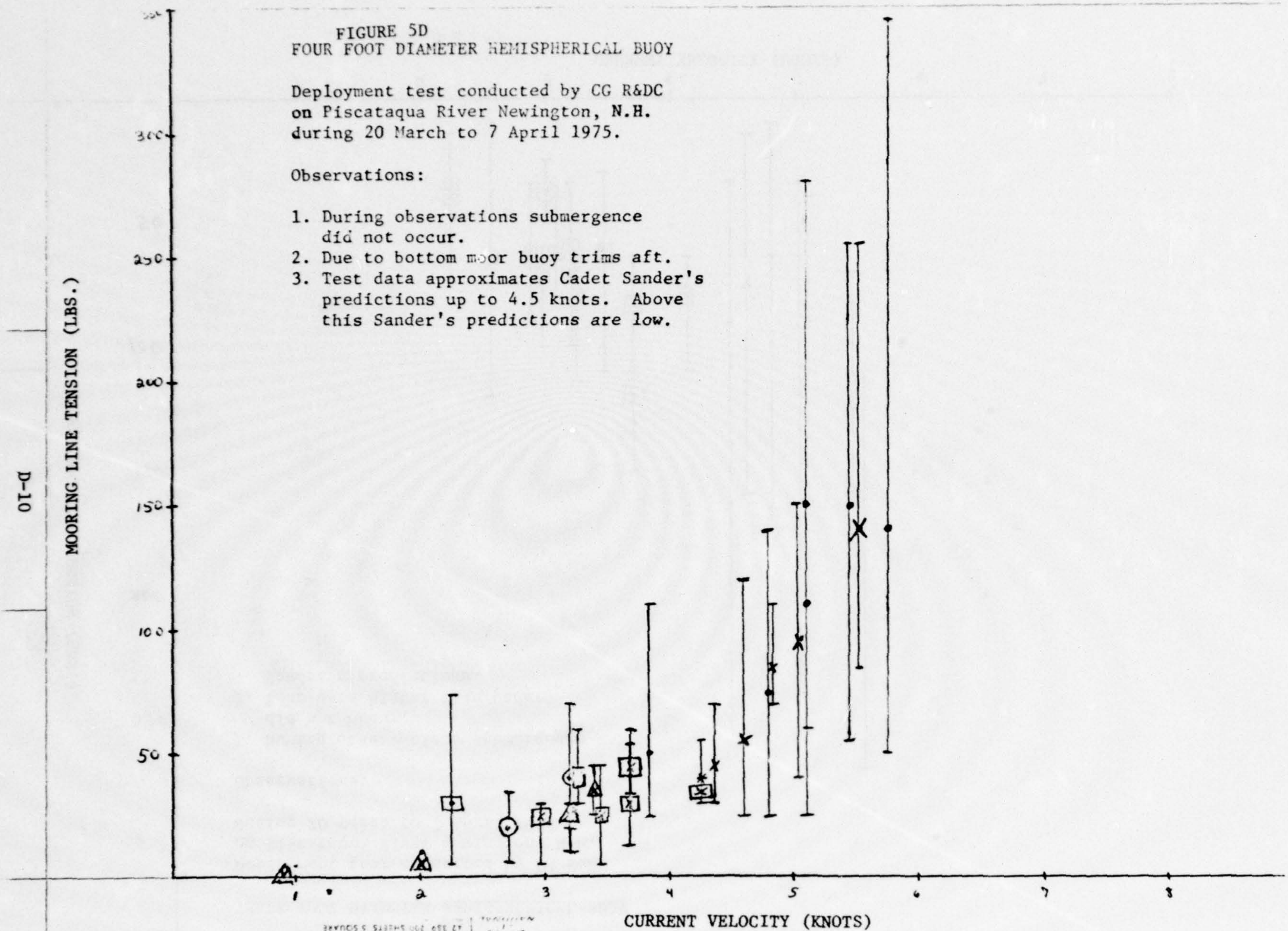
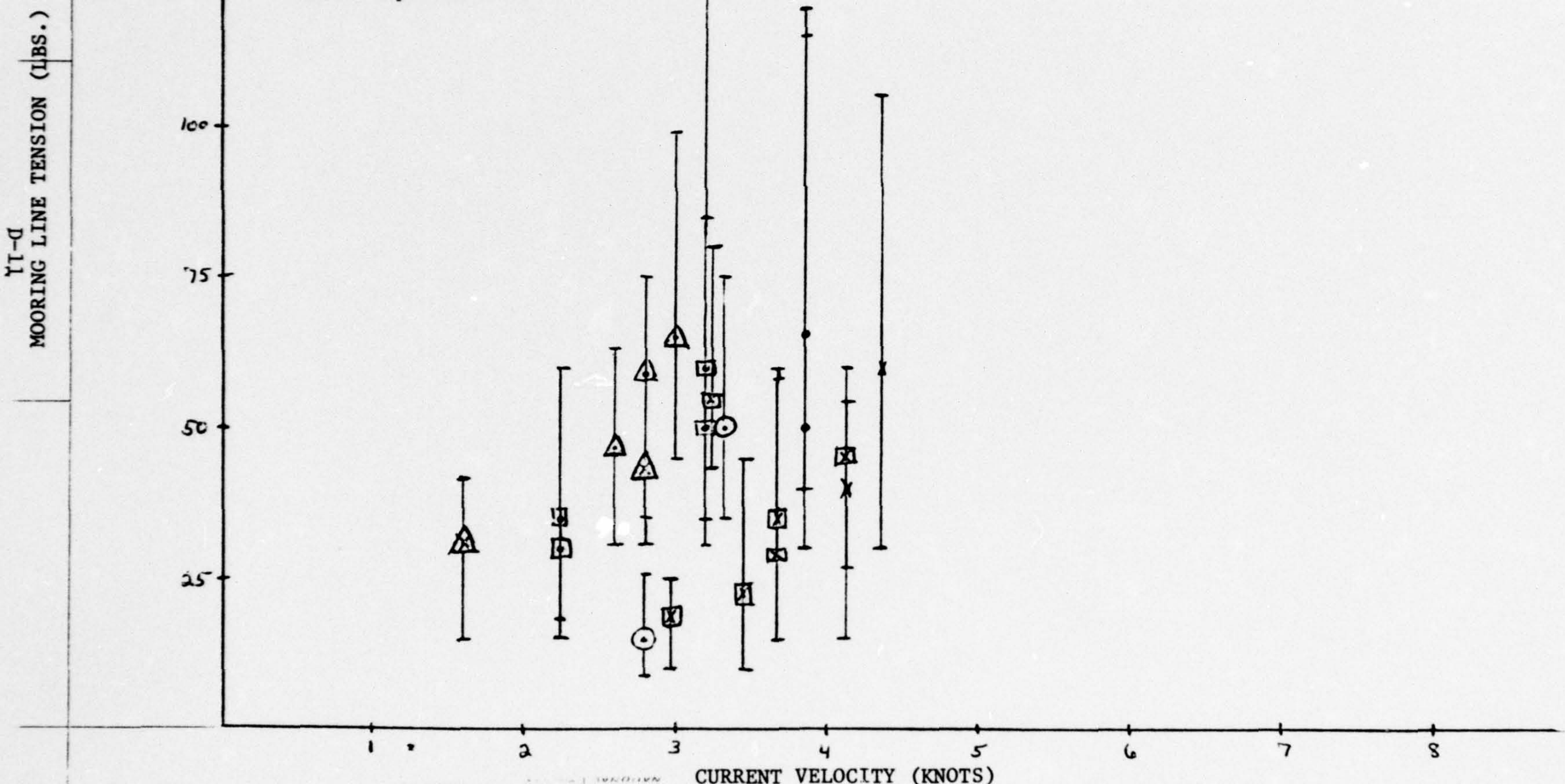


FIGURE 6D
THREE FOOT DIAMETER SPHERICAL BUOY

Deployment test conducted by CG R&DC on Piscataqua River Newington, N.H. during 20 March to 7 April 1975.

Observations:

1. During observations submergence did not occur.
2. Test data higher than Cadet Sanders predictions.



APPENDIX E
SIMPLIFIED COMPUTER MODEL

TABLE OF CONTENTS



LIST OF ILLUSTRATIONS



LIST OF TABLES

## E.1 INTRODUCTION

This simplified computer model was developed for use on an programmable hand calculator to evaluate (theoretically) the design/re-design process that lead to the prototype buoys. The analysis is an iterative converging solution of the inter-dependent vertical and horizontal forces on the buoys.

## E.2 METHODOLOGY

The analysis initially assumes a draft of the hull and from this computes the buoy's horizontal drag. The cable drag is computed and added to the buoy drag (and debris drag if included) to give the cumulative horizontal component of tension at the sinker. The vertical component of tension at the sinker is resolved from the horizontal component of tension and the scope (for a straight (taut) mooring line approximation). This vertical component is summed with the cable weight and the buoy weight to compute the buoyant force required to counteract the cumulative downward forces. Finally, a new draft is computed from the buoyant force required and is reinserted into the assumed initial draft for subsequent iterations until convergence is attained. By this analysis method, the draft, horizontal and vertical components of mooring line tension, and the resultant mooring line tension can be calculated as functions of the buoy size and weight, water depth, mooring line size and weight, mooring scope, debris drag, and current velocity.

## E.3 ASSUMPTIONS

In order to simplify calculations, these assumptions were made:

1. That the mooring material is cable (cylindrical; not chain) and is without catenary and can therefore be approximated by a straight line. This is a good approximation when the drag of the buoy (with or without debris) is great compared with either the drag on the cable or the weight of the cable. Tests of several buoys in a circulating water channel confirm that this assumption is valid for currents above 3 knots, scopes of 1.7 through 3.0, and wire rope of 1/4 inch diameter.

2. That the effect of wind is negligible.

3. A uniform velocity current profile exists.

4. That the sinker is fixed to the bottom.

5. That the analysis is limited to a two dimensional analysis of coplanar forces.

6. That the buoy maintains an upright orientation under all conditions.

7. That debris load is applied horizontally at the buoy's mooring attachment point without interference with the buoy.

8. That the buoy hull is a spherical section.

## E.4 APPROXIMATIONS

The following approximations were used in the model:

1. The drag on the cable is considered only in the direction of current flow and not along the cable.

2. The coefficient of drag for the cable is 1.2.

3. The coefficient of drag for the buoy is 2.0.

4. The coefficient of lift for the buoy is 0.0.

## E.5 ANALYSIS

The analysis of the system shown in Figure 1E is based on the following fundamentals:

1. The sum of the vertical forces on the system must be zero.

2. The sum of the horizontal forces on the system must be zero.

3. The relationship between the vertical and horizontal components of mooring cable tension is dependent on the mooring configuration.

The <u>vertical forces</u> acting within the system are briefly described below (a list of variables is provided in Table 1E).

Buoy weight (Bwt): independent variable

Buoy buoyancy (Bync): dependent variable
Buoyancy is equal to the weight of the water displaced by the buoy which is a function of buoy draft (Dft).

Cable weight (Cwt): independent variable

Sinker vertical force (Tvs): The vertical component of mooring cable tension at the sinker.

Since the sum of all vertical forces within the system must be zero, the following equation can be developed from Figure 1E:

$$\text{(e-1)} \qquad Tvs = Bync - Cwt - Bwt$$

The <u>horizontal forces</u> acting within the system are briefly described below:

Debris drag (Dd): independent variable

Buoy drag (Db): dependent variable
Buoy drag is determined from the basic drag equation:

$$\text{(e-2)} \qquad Db = \rho \ Cbd \ Pja \ Vel^2/2$$

where:

$\rho$ = density of water
Vel = current velocity
Pja = projected area of the below water portion of the buoy and is dependent on buoy draft (dft).
Cdb = coefficient of buoy drag

Cable drag: dependent variable
Cable drag is also determined from the basic drag equation and is dependent on three of the input parameters (Current velocity (Vel)), water depth (Dpth) and cable diameter (Dia).

(e-3) $$Dc = \rho \; Cdc \; Pca \; Vel^2/2$$

where:

Pca = projected area of the cable which is the product of the water depth and cable diameter.
Cdc = coefficient of cable drag

Sinker horizontal force (Ths): The horizontal component of mooring cable tension at the sinker.

Since the sum of all the horiztonal forces within the system must be zero, the following equation can be developed from Figure 1E:

(e-4) $$Ths = Dd + Db + Dc$$

The relationship between the vertical and horizontal components of mooring cable tension is dependent on the mooring configuration. Because a straight line approximation of mooring cable configuration is assumed in this model, the relationship of the components is dependent on scope, an independent variable.

(e-5) $$Tvs = Ths \; Tan \; [\text{arc sine } (^1/\text{scope})]$$

From Equations (e-1), (e-4), and (e-5) the interdependency of buoyancy with respect to buoy draft, and buoy drag with respect to buoy draft can be determined. The buoy draft is a function of the buoyancy required and effects the buoy drag which in turn effects the buoyancy required. For any steady state condition there exists a unique draft that will satisfy the equations.

The converging solution method was selected for determining the unique draft for each input condition. In this solution (the flow chart is shown in Figure 2E) a draft is assumed and a sequence of the above equations is used to determine a new estimate of the draft which is closer to the unique solution. After several iterations (about 10 depending on the accuracy of the first assumed value) the drafts do not change, hence, the solution of draft is reached, and the corresponding mooring tension components can be computed.

This analysis was conducted on a programable hand calculator although the method is applicable to other calculators or computers.

An example of the results from this analysis is given in Table 2E for the predicted performance of the five-foot prototype buoy. A parametric sensitivity using this analysis (Table 3E) was used to identify the important parameters in the design.

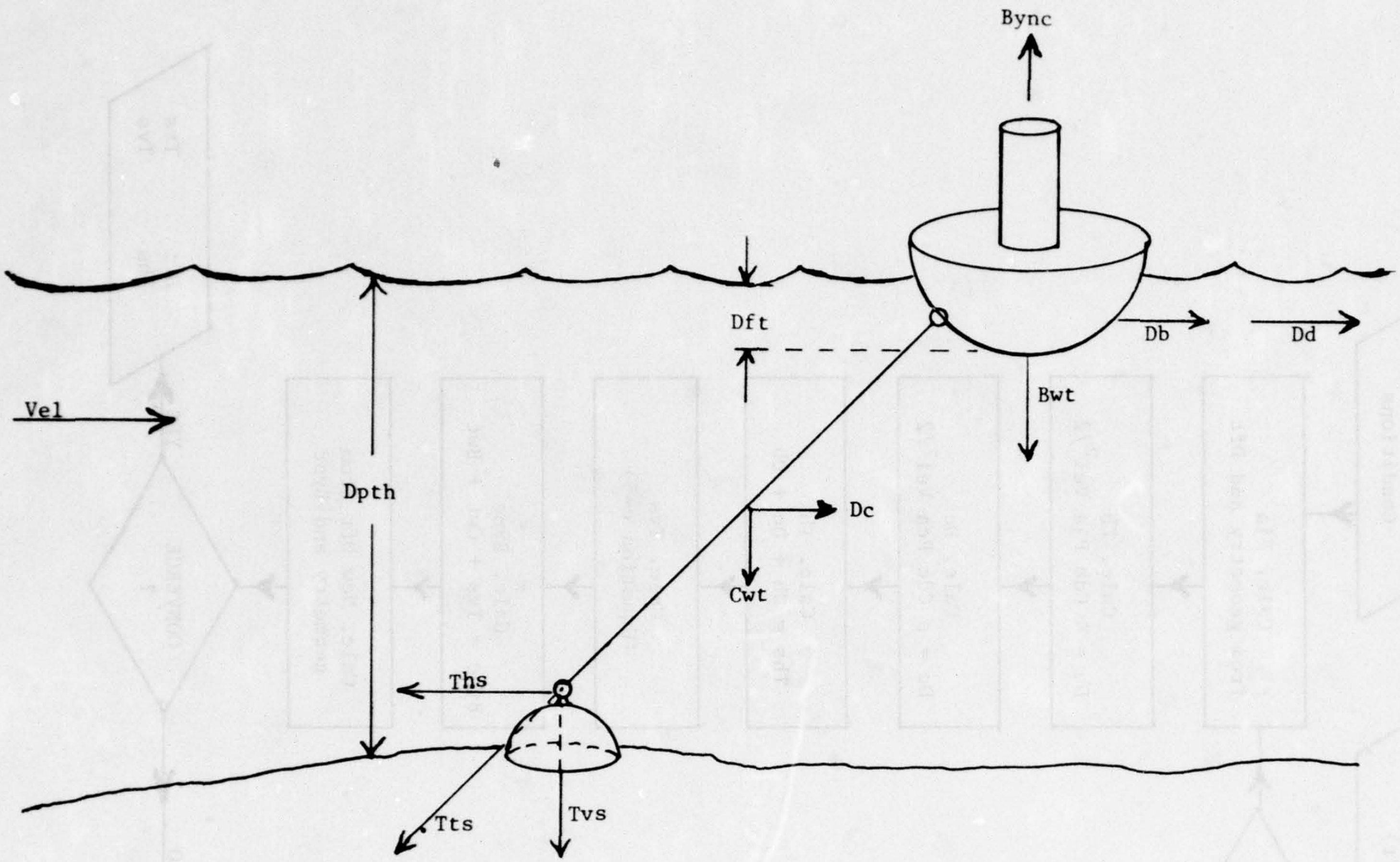



FIGURE 1E

SIMPLIFIED FW BUOY SYSTEM

FIGURE 2E

FLOW CHART OF FWB SYSTEM ANALYSIS

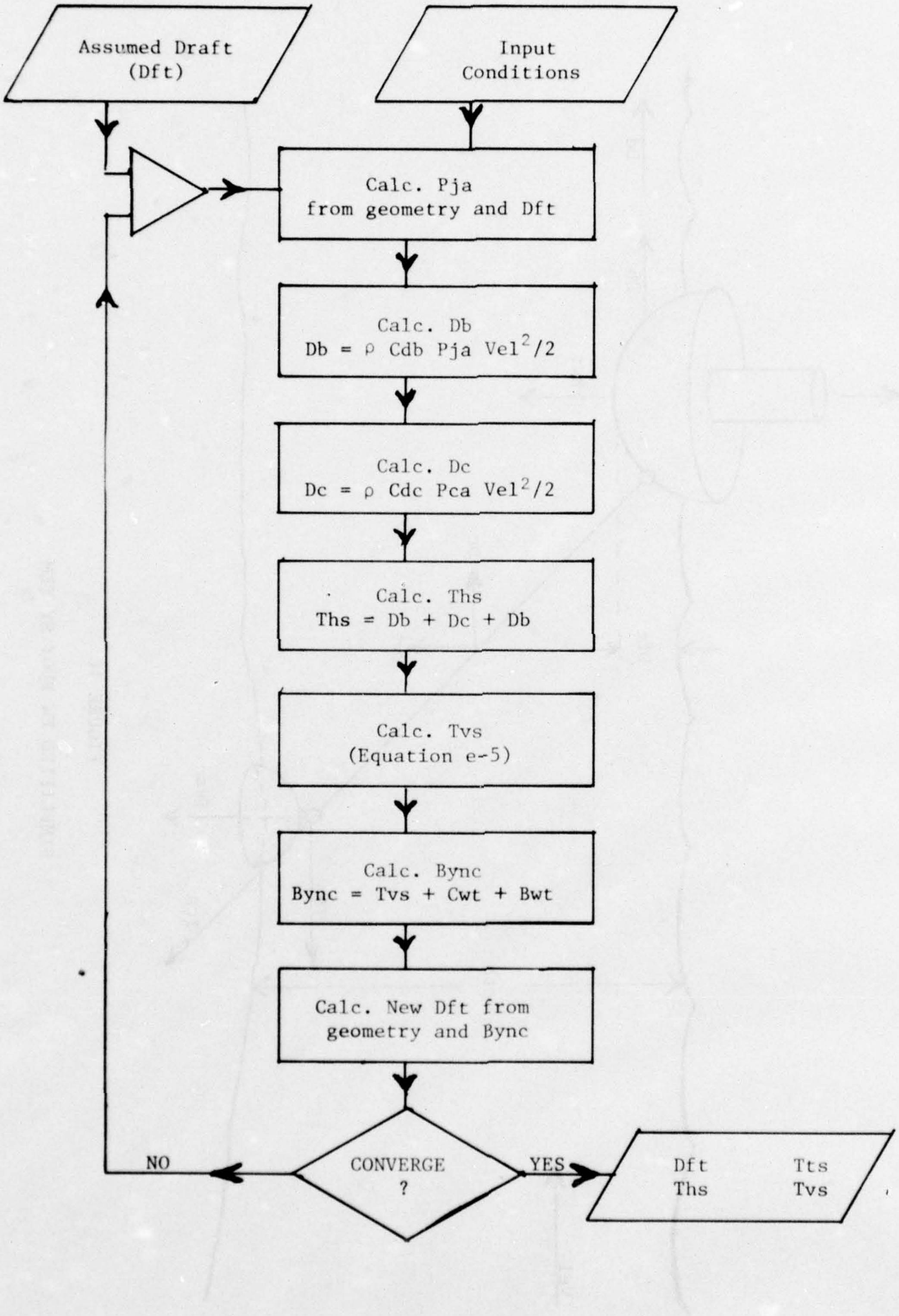


TABLE 1E

LIST OF VARIABLES

| | |
|---|---|
| α | Density of water |
| Bwt | Buoy weight |
| Bync | Buoyancy of the buoy |
| Cdb | Coefficient of buoy drag |
| Cdc | Coefficient of cable drag |
| Cwt | Cable weight |
| Db | Drag of the buoy |
| Dc | Drag of the cable |
| Dd | Drag of the debris |
| Dft | Draft of the hull |
| Dia | Cable diameter |
| Dpth | Water depth |
| Pca | Projected area of the cable |
| Pja | Projected area of the below waterline portion of the buoy hull |
| Rds | Radius of spherical section |
| Scp | Scope of mooring |
| Ths | Horizontal component of tension at the buoy |
| Tnb | Horizontal component of tension at the buoy |
| Ttb | Tension at the buoy |
| Tts | Tension at the sinker |
| Tvb | Vertical component of tension at the buoy |
| Tvs | Vertical component of tension at the sinker |
| Vel | Current velocity |

TABLE 2E

PREDICTED PERFORMANCE* OF THE FIVE-FOOT DIAMETER PROTOTYPE BUOY

| Vel (knots) | Tns (lbs.) | Tvs (lbs.) | Tts (lbs.) | Dft (feet) |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0.60 |
| 1 | 13 | 5 | 14 | 0.61 |
| 2 | 54 | 23 | 59 | 0.64 |
| 3 | 130 | 57 | 142 | 0.70 |
| 4 | 261 | 114 | 285 | 0.78 |
| 5 | 475 | 207 | 518 | 0.91 |
| 6 | 830 | 362 | 906 | 1.08 |
| 7 | 1428 | 623 | 1558 | 1.32 |
| 8 | 2425 | 1058 | 2646 | 1.65 |
| 9 | 4068 | 1775 | 4438 | 2.08 |
| 10** | 6519 | 2845 | 7113 | 2.59 |

*Initial conditions: Scope = 2.5:1; Cable (steel) diameter = 3/8 inches; Water depth = 45 feet; Buoy weight = 145 pounds; Radius of spherical section = 31.5 inches = 2.64 feet; Maximum draft (with no trim or list) = 27.5 inches = 2.29 feet.

**Since a draft of 2.59 feet is greater than the maximum draft of the buoy (2.29 feet), this line is erroneous.

TABLE 3E

PARAMETRIC SENSITIVITY* OF THE FIVE-FOOT DIAMETER PROTOTYPE BUOY

Sensitivity to variations in scope:

| Scope | Ths (pounds) | Tvs (pounds) | Tts (pounds) | Dft (feet) |
|---|---|---|---|---|
| 1.5 | 5573 | 4984 | 7477 | 3.38 |
| 2.0 | 3388 | 1955 | 3912 | 2.17 |
| 3.0 | 1965 | 695 | 2084 | 1.38 |
| 5.0 | 1325 | 270 | 1352 | 0.98 |

Sensitivitiy to variations in water depth:

| Water Depth (feet) | Ths (pounds) | Tvs (pounds) | Tts (pounds) | Dft (feet) |
|---|---|---|---|---|
| 10 | 1861 | 799 | 2025 | 1.46 |
| 20 | 2027 | 875 | 2208 | 1.52 |
| 60 | 2646 | 1160 | 2889 | 1.72 |
| 100 | 3214 | 1423 | 3515 | 1.88 |

Sensitivity to variations in buoy weight:

| Buoy Weight (pounds) | Ths (pounds) | Tvs (pounds) | Tts (pounds) | Dft (feet) |
|---|---|---|---|---|
| 100 | 2291 | 999 | 2499 | 1.58 |
| 200 | 2555 | 1115 | 2788 | 1.72 |
| 300 | 2778 | 1212 | 3031 | 1.85 |
| 400 | 2981 | 1302 | 3253 | 1.96 |

Sensitivity to variations in spherical section radius:

| Radius (feet) | Ths (pounds) | Tvs (pounds) | Tts (pounds) | Dft (feet) |
|---|---|---|---|---|
| 2 | 2566 | 1119 | 2799 | 1.98 |
| 3 | 2314 | 1010 | 2525 | 1.50 |
| 4 | 2058 | 898 | 2245 | 1.21 |

Sensitivity to variations in cable diameter:

| Cable Diameter (inches) | Ths (pounds) | Tvs (pounds) | Tts (pounds) | Dft (feet) |
|---|---|---|---|---|
| 1/8" | 1937 | 846 | 2114 | 1.49 |
| 1/4" | 2173 | 946 | 2370 | 1.56 |
| 1/2" | 2655 | 1159 | 2897 | 1.72 |
| 5/8" | 2902 | 1265 | 3166 | 1.80 |

Sensitivity to addition of debris drag:

| Debris Drag (pounds) | Ths (pounds) | Tvs (pounds) | Tts (pounds) | Dft (feet) |
|---|---|---|---|---|
| 350 | 3120 | 1362 | 3404 | 1.84 |
| 700 | 3772 | 1646 | 4116 | 2.01 |
| 1050 | 4395 | 1918 | 4795 | 2.15 |
| 2000 | 5971 | 2606 | 6515 | 2.48 |

*One parameter is varied at a time from the following initial conditions: Current velocity = 8 knots; Scope = 2.5:1; Cable (steel) diameter = 3/8 inches; Water depth = 45 feet; Buoy weight = 145 pounds; Radius of spherical section = 2.63 feet; Maximum draft = 2.29 feet.

APPENDIX F

SPECIFICATIONS AND DRAWINGS OF THE
FRN3, FCR3, FNR4, AND FCR4 BUOYS

OCEAN ENGINEERING DIVISION
UNITED STATES COAST GUARD

WASHINGTON, D.C.

APRIL 1976

SPECIFICATION FOR UNLIGHTED
PLASTIC FAST WATER BUOY
TYPE FNR3 AND FCR3

PURCHASE DESCRIPTION NO. 296

SPECIFICATION FOR UNLIGHTED PLASTIC FAST WATER BUOY

1.0 SCOPE

1.1 General: This specification covers the requirements for unlighted plastic fast water buoys for use as aids to navigation in navigable water of the United States. The buoys shall be furnished either with black CAN daymarks and hulls or red NUN daymarks and hulls.

1.2 Classification: Buoys with CAN daymarks are classified as FCR3 buoys and buoys with NUN daymarks are classified as FNR3 buoys.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids forms a part of this specification to the extent specified herein. In the event of conflict between the detailed requirements of this specification and those of supporting documents, this specification shall govern.

Specifications:

Military

MIL-P-21929 - Plastic material, cellular polyurethane, rigid foam in place

MIL-P-116 - Preservation - packaging, methods of

Standards:

Federal

Federal Standard Number 595 - Colors

Copies of Federal and Military Specifications and Standards may be obtained from Commanding Officer, U. S. Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120, ATTN: (CDS). All requests for copies of such publications should stipulate both title and identifying number of each desired publication.

2.2 Other Publications: The following documents of the issue in effect on date of invitation for bids form a part of this specification to the extent specified herein. In the event of conflict between the detailed requirements of this specification and those of supporting documents this specification shall govern.

American Society for Testing Materials (ASTM)

D-638-72 - Tensile Properties of Plastics

D-746-70T - Brittleness Temperature of Plastic and Elastomers by Impact

D-1505-68 - Density of Plastics by the Density Gradient Technique

D-1693-70 - Environmental Stress-Cracking of Ethylene Plastics

D-2765-68 - Degree of Crosslinking in Crosslinked Ethylene Plastic as Determined by Solvent Extraction

Application for copies should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

3.0 REQUIREMENTS

3.1 General: The buoy hull and the buoy daymark shall be constructed of plastic materials with steel mooring fittings and through rods and an aluminum radar reflector. The dimensions of all components of the buoy are shown in Ocean Engineering Drawing No. 120754 which shall be referred to as "the drawing" throughout this specification. The drawing forms a part of this specification; however, where notation on the drawing conflicts with this specification, this specification shall govern.

3.2 Materials

3.2.1 Buoy Shell: The shell of the buoy hull and daymark shall be fabricated using high density, crosslinked, polyethylene plastic. After molding and cure, the material shall meet the following requirements:

a. It shall be composed of 100 percent virgin material.

b. It shall have a maximum density of .939 grams per cubic centimeter, determined in accordance with ASTM Specification D-1505-68, "Density of Plastics by the Density Gradient Technique."

c. It shall have an environmental stress cracking resistance for the 50 percent failure point ($F_{50}$) of greater than 1000 hours, determined in accordance with ASTM Specification D-1693-70, "Environmental Stress - Cracking of Ethylene Plastics."

d. It shall have an ultimate tensile strength of at least 2600 pounds per square inch, determined in accordance with ASTM Specification D-638-72, "Tensile Properties of Plastic," at a speed of testing of 2 inches per minute (Speed C).

e. It shall have a minimum elongation at break of 450 percent, determined in accordance with ASTM Specification D-638-72, "Tensile Properties of Plastics" at a speed of testing of 2 inches per minute (Speed C).

f. It shall have a brittleness temperature of less than -180°F, determined in accordance with ASTM Specification D-746-70T, "Brittleness Temperature of Plastic and Elastomers by Impact."

g. The maximum percent of extract as determined in accordance with ASTM Specification D-2765-68, "Degree of Crosslinking in Crosslinked Ethylene Plastics as Determined by Solvent Extraction," Method A or B, shall not exceed 13 percent.

h. Ultraviolet stabilizers shall compose at least 0.5 percent of the red material after molding. No ultraviolet stabilizers need be used in the black resin.

The name of the supplier, the supplier's designation of the resin, and a full description of the as-molded physical characteristics of the resin shall be submitted to the Government after contract award.

3.2.2 Foam: The hull portion of the buoy, as indicated in the drawing, shall be completely foam filled with a rigid closed-cell polyurethane foam of 2.0 pounds per cubic foot density, meeting the requirements of Military Specification MIL-P-21929, "Plastic Material, Cellular Polyurethane Rigid Foam in Place," Class 1. Foaming shall be made through an opening in the buoy body 1 to 2 inches in diameter. This hole shall be located on top of the hull, under the daymark, as shown in the drawing.

3.2.3 Metal Hardware

3.2.3.1 Radar Reflector; Each buoy daymark shall contain an aluminum radar reflector connected to the radar reflector rod, as shown in the drawing. Since the radar reflector is not a strength component of the buoy, any standard grade commercial sheet aluminum, 0.0625 inches thick, is acceptable. The radar reflector shall be assembled using bead welds, spot welds, rivets, screws, or any other method which will provide the necessary rigidity and strength to maintain the 90 degree angles, plus or minus 1 degree between any two plates. Brass fasteners shall not be used.

3.2.3.2 The counterweight rod, mooring rod, anchor plate, lifting eye rod, lifting eye and radar reflector rod shall be of standard grade commercial steel, with a minimum tensile strength of 58,000 PSI, a yield point of at least 36,000 PSI, and a minimum elongation, at 2 inches, of 23 percent. All threads on the rods shall be National Coarse (NC) threads, as shown on the drawing.

3.2.3.3 The nuts, washers, mooring eye, screws, threaded insert and counterweight shall be of a compatible commercial grade of steel.

3.2.4 The Contractor shall furnish a certificate of conformance either from the material manufacturer or a reputable engineering laboratory to the effect that all materials described in Section 3.2.1, 3.2.2, and 3.2.3.2 have been tested and found to be in accordance with the requirements of Section 3.2.1, 3.2.2, and 3.2.3.2 of this specification, as applicable.

3.3 Design and Dimension: The CAN and NUN buoys shall conform in design and dimension to the drawing.

3.3.1 Dimension Tolerances: The dimension tolerances shall be as given on the drawing.

3.4 Color: Color compounding shall be used to give the NUN buoy a red color and the CAN buoy a black color. The black color shall be Federal Color Number

17038 from Federal Standard Number 595. The red color shall fall within the range of colors defined by the two color samples below:

1 2

3.5 Weld Quality: A basic requirement of all welds is thorough fusion of weld and base metal and of successive layers of weld metal. Welds should not be handicapped by craters, undercutting, overlap, porosity, or cracks.

3.6 Workmanship: The completed buoy shall be free of any cracks, wrinkles, holes or gouges. The color and finish of the buoy are to be uniform and free of foreign matter. Extra material at the parting lines shall be removed. Any parting agent residue on the surface of the buoy shall be removed. The surface finish shall be smooth.

3.7 Marking: Buoys shall be permanently marked with three lines of alpha-numeric characters which shall be located on the top flat part of the hull, as shown in the drawing. Block digits at least 3/4 inch high and not higher than 1 inch shall be used for letters and numerals. The first line of this marking shall be the letters "USCG". The second line on buoys with NUN daymarks shall be the letters and number "FNR3". The second line on buoys with CAN daymarks shall be the letters and number "FCR3". The third line shall be the numeric digit(s) for month built and the last two digits of the year built, separated by a dash. After contract award, a two-letter code will be assigned to the Contractor by the Contracting Officer. This two-letter manufacturer's code shall form a part of the third line and shall be separated from the date built by a space. Permanent markings shall be molded or engraved into the hull.

3.8 Preproduction Sample: Before production is commenced, there shall be a preproduction run of one complete CAN buoy and one complete NUN buoy. The preproduction samples shall be manufactured in the same facilities to be used for quantity production. Quantity production shall not be initiated until the preproduction samples have been inspected and approved.

## 4.0 QUALITY ASSURANCE PROVISIONS

4.1 The Contractor shall be responsible for the conduct of all tests required by the contract. He shall provide all space, personnel, and test equipment necessary for the conduct of the tests. The Contractor shall notify the Contracting Officer ten (10) days prior to the commencement of any of the tests required by contract. This testing will be witnessed by a Government Representative. Any buoys subjected to destructive testing shall not be included as deliverables under the contract.

### 4.2 Preproduction Inspection

4.2.1 General: The Government Representative will inspect the preproduction samples for conformance to this specification. This inspection will include the measurement of some or all dimensions to insure they are within the specified tolerance. Preproduction inspection will also include a check of

exterior color, surface finish, external weld quality and workmanship. The tests and inspections outlined in Sections 4.2.2, 4.2.3, 4.2.4 and 4.2.5 below will also be performed.

4.2.2 Strength of Hardware Test: A 3000 pound load shall be applied between the lifting tee and mooring eye. If permanent deformation of the steel hardware results due to manufacturing defect in material, weld, or fabrication, the buoy shall be considered to have failed the test.

4.2.3 Shell Thickness: The shell thickness of the buoy hull and daymark shall be measured by cutting the hull and daymark into equal quarters, and using a micrometer, measuring the thickness of the shell along the cutting lines. If the shell thickness falls outside the specified tolerances, the buoy shall be considered to have failed the test.

4.2.4 Foam Voids and Quality: The same hull that is cut open to check the shell thickness shall also be examined for foam voids and foam quality. Any foam void larger than 6 inches in diameter shall cause the buoy to be considered to have failed the test. Foam samples taken from the buoy hull shall be subjected to the tests outlined in MIL-P-21929 to determine the conformance. Failure of the sample to conform to MIL-P-21929 shall cause the buoy to be considered to have failed the test.

4.2.5 Crosslinking of Shell Material: Samples of the buoy shell material shall be subjected to the tests outlined in ASTM Specification D-2765-68, Method A or B, to determine the percent of extract. Alternate methods for determining this percentage may be used if found acceptable to the Government Representative. If the percent of extract is in excess of 13 percent, the buoy shall be considered to have failed the test.

4.2.6 Rejection of Preproduction Samples: If the preproduction sample fails any one of the inspections of tests outlined in Section 4.2.1, 4.2.2, 4.2.3, 4.2.4, and 4.2.5, the sample shall be rejected. Quantity production shall not be initiated until the preproduction sample has been inspected and approved.

## 4.3 Production Inspection

4.3.1 Production Sampling: Samples for inspection of these buoys shall be selected from each lot in accordance with Table 1.

TABLE 1

| Number of Buoys in Lot | Number of Samples | Acceptance Number |
|---|---|---|
| 2-8 | 3 | 0 |
| 9-15 | 5 | 0 |
| 16-25 | 8 | 1 |
| 26-50 | 13 | 1 |
| 51-90 | 20 | 2 |
| 91-150 | 32 | 3 |
| 151-280 | 50 | 5 |
| 281-500 | 80 | 7 |

4.3.2 Lot: For the purpose of inspection of these buoys, a lot shall consist of all items of the same class (CAN or NUN) offered for inspections at the same time. There shall be no more than four lots of CAN buoys and no more than four lots of NUN buoys.

4.3.3 Inspection: Samples selected in accordance with Section 4.3.1 will be inspected by the Government Representative to determine conformance to this specification. The inspection will include the measurement of some or all dimensions to insure they are within the specified tolerances. Inspection will also include a check of color, surface finish, external weld quality and workmanship. One buoy from each lot shall be subjected to the strength of hardware test outlined in Section 4.2.2. If this buoy fails the test, all samples selected in accordance with Section 4.3.1 shall be subjected to the test.

4.3.4 Rejections: If the cumulative number of defective samples is equal to or less than the acceptance number shown in Table 1, the lot will be accepted. If the number of the defective samples exceeds the acceptance number, a second set of samples shall be selected, in an amount doubling that taken originally, and the acceptance number shall also be doubled except where that acceptance number is zero, in which case it shall become one. If the number of defective samples exceeds the second acceptance number, the lot shall be rejected.

4.3.5 Shell Material Testing: Section 3.2.2 of this specification requires the cutting of a 1- to 2-inch diameter hole in the buoy hull, on the flat part of the deck as shown in the drawing. This hole shall be cut with a drill-mounted hole cutter and the plastic plug that is removed shall be saved. The Government Representative will require that samples of the plug selected in accordance with Table 1 be subjected to testing to determine the level of crosslinking and conformance to the requirements of Section 3.2.1 of this specification. Rejections of the lot shall be as outlined in Section 4.3.4 of this specification.

## 5.0 PREPARATION FOR DELIVERY

5.1 General: The buoys shall be shipped in three separate pieces; the hull assembly, the daymark, and the radar reflector assembly. The number of black hulls, CAN daymarks, and CAN radar reflector assemblies shipped at any one time must be equal. The number of red hulls, NUN daymarks, and NUN radar reflector assemblies shipped at any one time must be equal.

### 5.2 Packaging

5.2.1 Hull Assembly: The hull assembly does not require packaging or preservation prior to shipment.

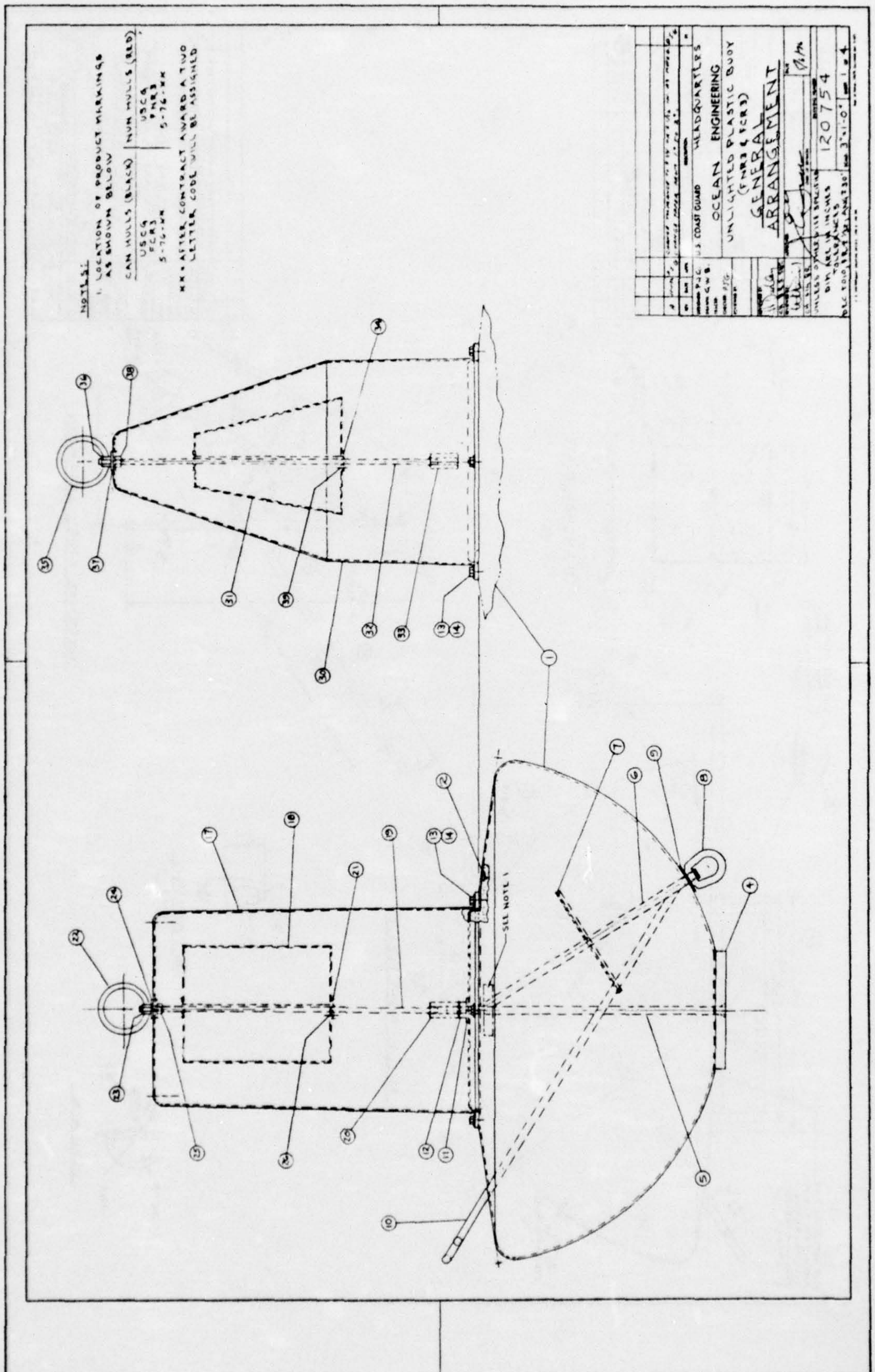
5.2.2 Daymarks: The daymarks do not require packaging or preservation prior to shipment. However, if the daymarks are stacked one on top of another, a spacer shall be placed between the daymarks such that sticking does not occur. If daymarks are stacked, the number of daymarks shall not exceed ten (10) in any one stack and at no time shall CAN and NUN daymarks be mixed in a stack.

5.2.3 Radar Reflector Assembly: These items shall be packaged for shipment in accordance with Military Specification MIL-P-116, Method III, for domestic shipment. No preservation is required. The number of radar reflector assemblies in any one package shall not exceed ten (10) and at no time shall CAN and NUN radar reflector assemblies be mixed in one packaged.

5.3 Marking: The marking of the buoy hull is as outlined in Section 3.7. The daymark does not require any marking. The NUN radar reflector assemblies package shall be marked with the words "NUN Radar Reflector Assembly". The CAN radar reflector assemblies package shall be marked with the words "CAN Radar Reflector Assembly". In both cases the quantity of assemblies in each package shall also be marked.

6.0 NOTES

6.1 Destructive Testing: The preproduction inspection includes destructive testing of one complete CAN buoy and one complete NUN buoy. If a buoy fails the testing, a second destructive test on another preproduction sample will be required. Any buoy subjected to destructive testing shall not be included as a deliverable under the contract. However, salvagable parts (steel work) may be used, if undamaged, in production.


NOTES:
1. LOCATION OF PRODUCT MARKINGS AS SHOWN BELOW
CAN HULLS (BLACK)
USCG
FCR3
5-76-XX
NUN HULLS (RED)
USCG
FNR3
5-76-XX
XX - AFTER CONTRACT AWARD A TWO LETTER CODE WILL BE ASSIGNED
SEE NOTE 1
U.S. COAST GUARD
HEADQUARTERS
OCEAN ENGINEERING
UNLIGHTED PLASTIC BUOY
(FNR3 & FCR3)
GENERAL
ARRANGEMENT
120754

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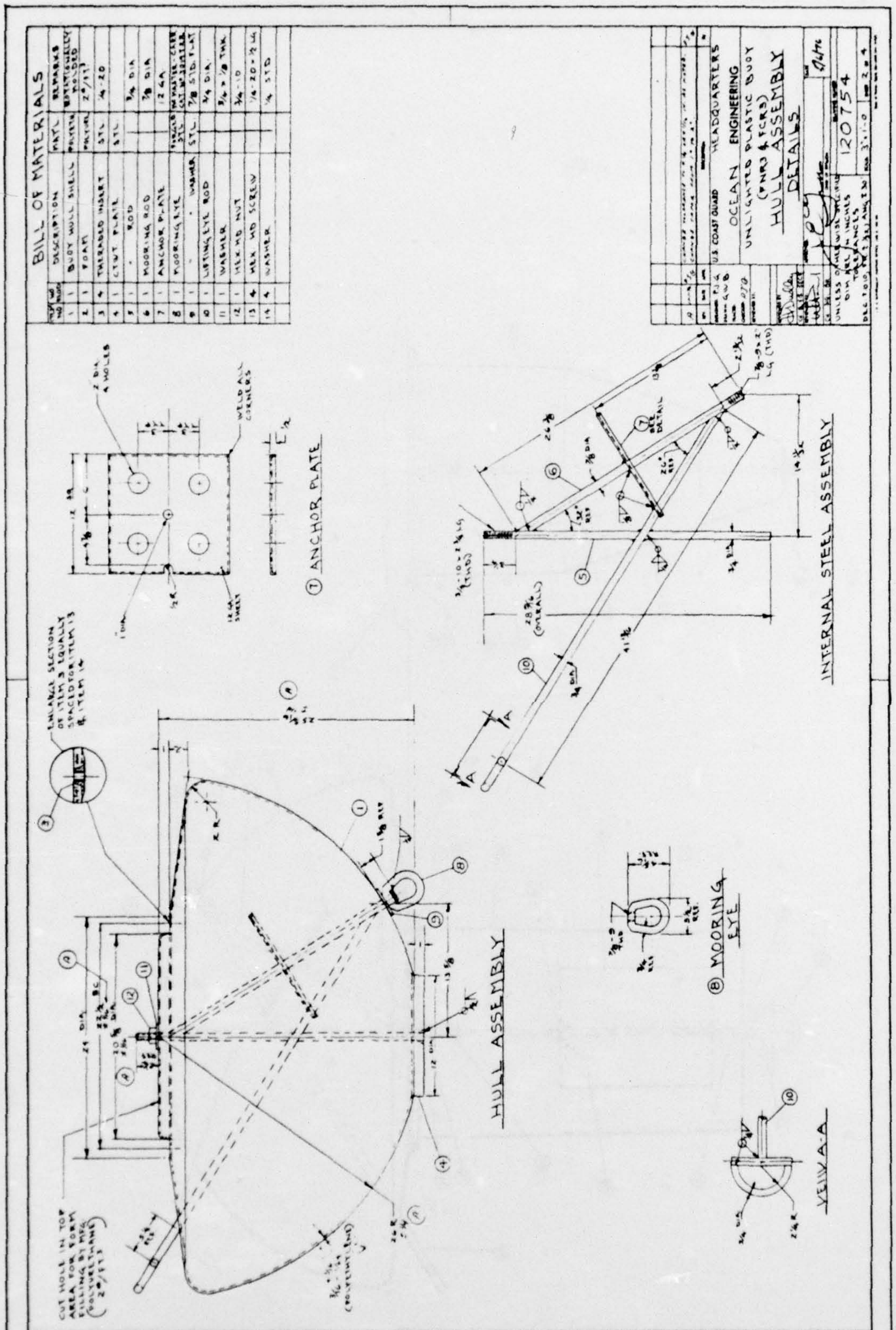
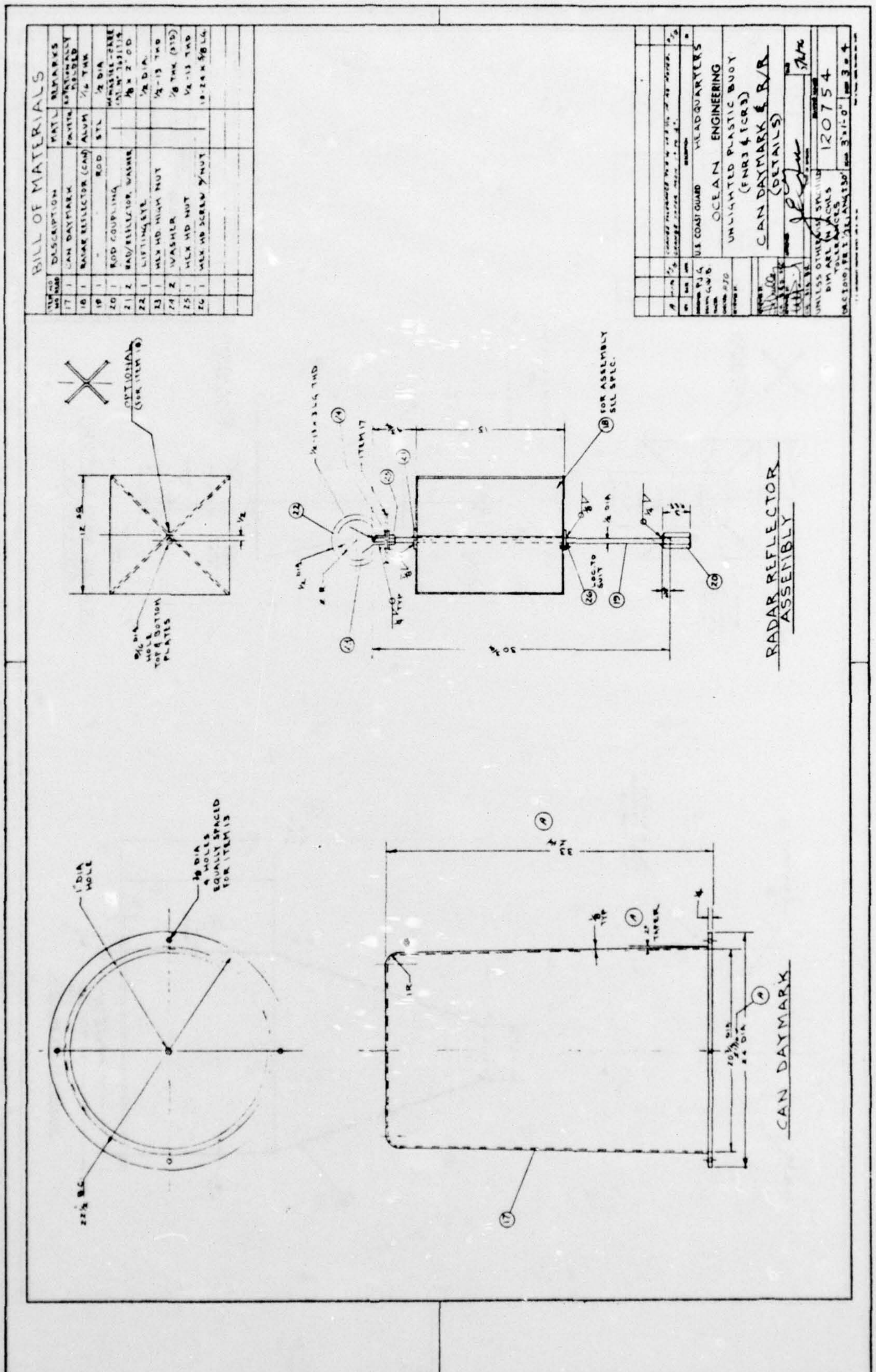
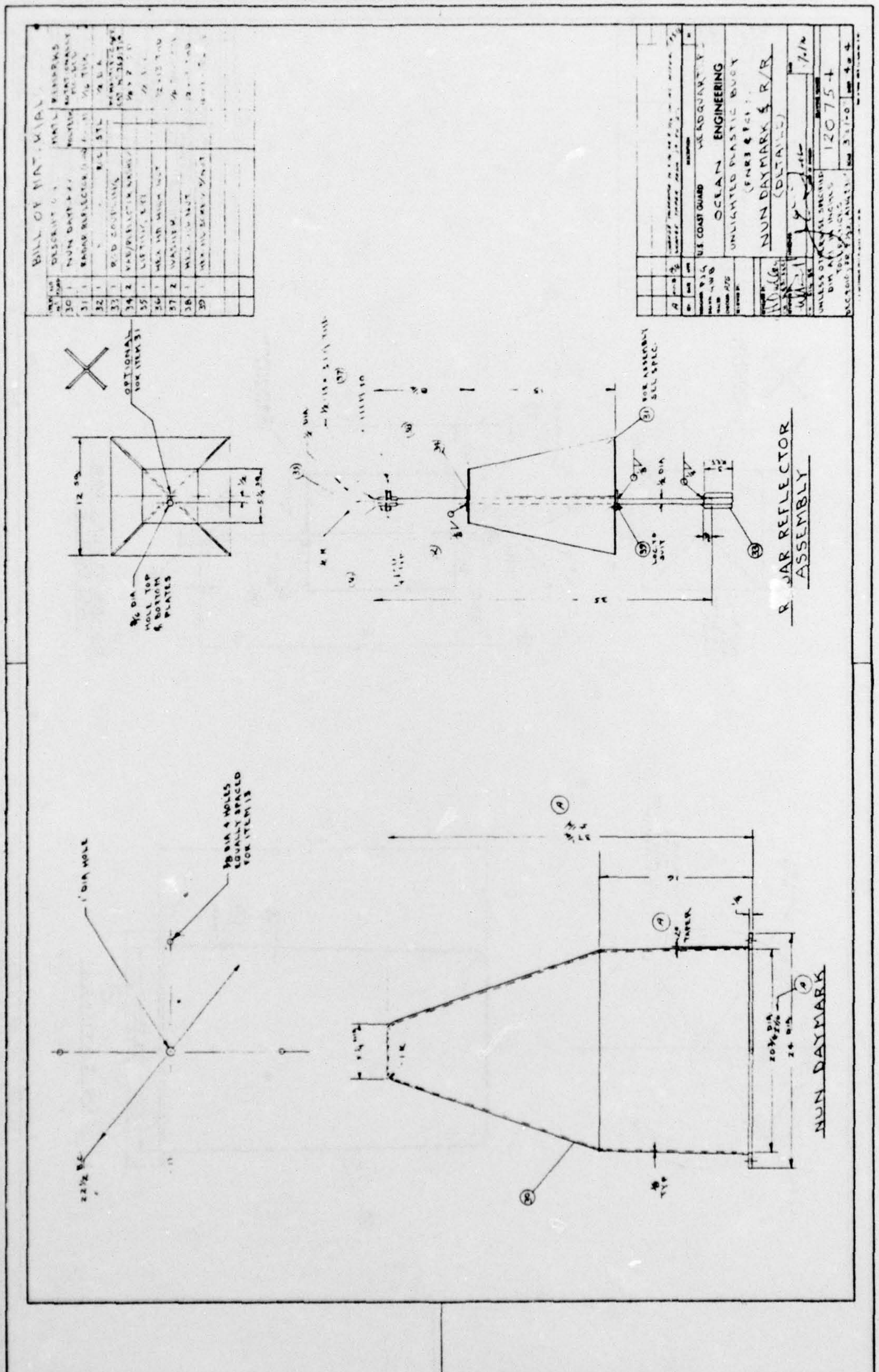



BILL OF MATERIALS
ITEM NO | NO REQD | DESCRIPTION | MAT'L | REMARKS
17 | 1 | CAN DAYMARK | POLYETH | ROTATIONALLY MOLDED
18 | 1 | RADAR REFLECTOR (CAN) | ALUM | 1/16 THK
19 | 1 | ROD | STL | 1/2 DIA
20 | 1 | ROD COUPLING | | MCMASTER-CARR CAT. Nº 7631T19
21 | 2 | RAD/REFLECTOR, WASHER | | 1/8 x 2" OD
22 | 1 | LIFTING EYE | | 1/2 DIA.
23 | 1 | HEX HD. HIGH NUT | | 1/2-13 THD
24 | 2 | WASHER | | 1/8 THK (STD)
25 | 1 | HEX HD NUT | | 1/2-13 THD
26 | 1 | HEX HD SCREW W/NUT | | 10-24 x 5/8 LG
22 1/2 B.C.
1" DIA HOLE
3/8 DIA 4 HOLES EQUALLY SPACED FOR ITEM 13
12 SQ
9/16 DIA HOLE TOP & BOTTOM PLATES
OPTIONAL (FOR ITEM 18)
1/2
1/2 DIA
1/2-13 x 3 LG THD
ITEM 17
1R
33 3/4
1/8 TYP
2° TAPER
20 1/2 DIA
24 DIA
CAN DAYMARK
30 3/8
15
LOC TO SUIT
1/2 DIA
FOR ASSEMBLY SEE SPEC.
RADAR REFLECTOR ASSEMBLY
U.S. COAST GUARD HEADQUARTERS
OCEAN ENGINEERING
UNLIGHTED PLASTIC BUOY
(FNR3 & FCR3)
CAN DAYMARK & R/R
(DETAILS)
PJG
GWB
UNLESS OTHERWISE SPECIFIED DIM ARE IN INCHES TOLERANCES
120754
3" x 1'-0"
3 of 4

BEST AVAILABLE COPY



OCEAN ENGINEERING DIVISION
UNITED STATES COAST GUARD

WASHINGTON, D.C.

SEPTEMBER 1976

SPECIFICATION FOR UNLIGHTED
PLASTIC FAST WATER BUOY
TYPE FNR4 AND FCR4

PURCHASE DESCRIPTION NO. 302

SPECIFICATION FOR UNLIGHTED PLASTIC FAST WATER BUOY

1.0 SCOPE

1.1 General: This specification covers the requirements for unlighted plastic fast water buoys for use as aids to navigation in navigable water of the United States. The buoys shall be furnished either with black CAN daymarks and hulls or red NUN daymarks and hulls.

1.2 Classification: Buoys with CAN daymarks are classified as FCR4 buoys and buoys with NUN daymarks are classified as FNR4 buoys.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids forms a part of this specification to the extent specified herein:

Specifications:

Military

MIL-P-21929 - Plastic material, cellular polyurethane, rigid foam in place

MIL-P-116 - Preservation - packaging, methods of

Federal

QQ-S-763 - Steel bars, wire, shapes, and forgings, corrosion-resisting

Standards:

Federal

Federal Standard Number 595 - Colors

In the event of conflict between the detailed requirements of this specification and those of supporting documents, this specification shall govern. Copies of Federal and Military Specifications and Standards may be obtained from Commanding Officer, U. S. Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120, ATTN: (CDS). All requests for copies of such publications should include both title and identifying number of each publication.

2.2 Other Publications: The following documents of the issue in effect on date of invitation for bids form a part of this specification to the extent specified herein.

American Society for Testing Materials (ASTM)

D-638-72 - Tensile Properties of Plastics

D-746-70T - Brittleness Temperature of Plastic and Elastomers by Impact

A-308-66 - Spectrophotometry and Description of Color in CIE 1931 System

D-1505-68 - Density of Plastics by the Density Gradient Technique

D-1693-70 - Environmental Stress-Cracking of Ethylene Plastics

D-2765-68 - Degree of Crosslinking in Crosslinked Ethylene Plastic as Determined by Solvent Extraction

In the event of conflict between the detailed requirements of this specification and those of supporting documents, this specification shall govern. Application for copies of these ASTM publications should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

3.0 REQUIREMENTS

3.1 General: The buoy hull and the buoy daymark shall be constructed of plastic materials with steel mooring fittings and through rods and an aluminum radar reflector. The dimensions of all components of the buoy are shown in Ocean Engineering Drawing No. 120760 which shall be referred to as "the drawing" throughout this specification. The drawing forms a part of this specification; however, where notation on the drawing conflicts with this specification, this specification shall govern.

3.2 Materials

3.2.1 Buoy Shell: The shell of the buoy hull and daymark shall be fabricated using high density crosslinked polyethylene plastic. After molding and cure, the material shall meet the following requirements:

a. It shall be composed of 100 percent virgin material.

b. It shall have a maximum density of .939 grams per cubic centimeter, determined in accordance with ASTM Specification D-1505-68, "Density of Plastics by the Density Gradient Technique."

c. It shall have an environmental stress-cracking resistance for the 50 percent failure point ($F_{50}$) of greater than 1000 hours, determined in accordance with ASTM Specification D-1693-70, "Environmental Stress - Cracking of Ethylene Plastics."

d. It shall have an ultimate tensile strength of at least 2600 pounds per square inch determined in accordance with ASTM Specification D-638-72, "Tensile Properties of Plastic," at a speed of testing of 2 inches per minute (Speed C).

e. It shall have a minimum elongation at break of 450 percent, determined in accordance with ASTM Specification D-638-72, "Tensile Properties of Plastics" at a speed of testing of 2 inches per minute (Speed C).

f. It shall have a brittleness temperature of less than -180°F, determined in accordance with ASTM Specification D-746-70T, "Brittleness Temperature of Plastic and Elastomers by Impact."

g. The maximum percent of extract as determined in accordance with ASTM Specification D-2765-68, "Degree of Crosslinking in Crosslinked Ethylene Plastics as Determined by Solvent Extraction," Method A or B, shall not exceed 13 percent.

h. Ultraviolet stabilizers shall compose at least 0.5 percent of the red material after molding. No ultraviolet stabilizers need be used in the black resin.

The name of the supplier, the supplier's designation of the resin, and a full description of the as-molded physical characteristics of the resin shall be submitted to the Government after contract award.

3.2.2 Foam: The hull portion of the buoy, as indicated in the drawing, shall be completely foam filled with a rigid closed-cell polyurethane foam of 2.0 pounds per cubic foot density, meeting the requirements of Military Specification MIL-P-21929, "Plastic Material, Cellular Polyurethane Rigid Foam in Place," Class 1. Foaming shall be made through an opening in the buoy body, 1 to 2 inches in diameter. This hole shall be located on top of the hull, under the daymark, as shown in the drawing.

3.2.3 Metal Hardware

3.2.3.1 Radar Reflector; Each buoy daymark shall contain an aluminum radar reflector connected to the radar reflector rod, as shown in the drawing. Since the radar reflector is not a strength component of the buoy, any standard grade commercial sheet aluminum, 0.0625 inches thick, is acceptable. The radar reflector shall be assembled using bead welds, spot welds, rivets, screws, or any other method which will provide the necessary rigidity and strength to maintain the 90 degree angles, plus or minus 1 degree between any two plates. Brass fasteners shall not be used.

3.2.3.2 The mooring rod, anchor plate, lifting eye and anchor plate rod shall be of standard grade commercial steel, with a minimum tensile strength of 58,000 PSI, a yield point of at least 36,000 PSI, and a minimum elongation, at 2 inches, of 23 percent. All threads on the rods shall be National Coarse (NC) threads, as shown on the drawing.

3.2.3.3 The nuts, washers, mooring eye, screws, and threaded insert shall be of a compatible commercial grade of steel.

3.2.3.4 The bolts and washers used to attach the daymark shall be stainless steel type 316, in accordance with the requirements of Federal Specification QQ-S-763.

3.2.4 The Contractor shall furnish a certificate of conformance either from the material manufacturer or a reputable engineering laboratory to the effect that all materials described in Section 3.2.1, 3.2.2, 3.2.3.2, and 3.2.3.4 have been tested and found to be in accordance with the requirements of Sections 3.2.1, 3.2.2, 3.2.3.2, and 3.2.3.4 of this specification, as applicable.

3.3 Design and Dimension: The CAN and NUN buoys shall conform in design and dimension to the drawing.

3.3.1 Dimension Tolerances: The dimension tolerances shall be as given on the drawing.

3.4 Color: Color compounding shall be used to give the NUN buoy a red color and the CAN buoy a black color. The color shall be throughout the thickness of the polyethylene shell material. The black color shall be Federal Color Number 17038 from Federal Standard Number 595. The red color shall fall within the boundaries defined by the four chromaticity points below, when plotted on the 1931 CIE chromaticity diagram from ASTM Specification E-308-66 and illuminated with illuminant "C":

| Point | Chromaticity Coordinates | | Luminance Minimum Y |
|---|---|---|---|
| | x | y | Y |
| 1 | .595 | .316 | .10 |
| 2 | .653 | .316 | .10 |
| 3 | .571 | .337 | .10 |
| 4 | .625 | .337 | .10 |

Color Sample 1 provided below falls on the line connecting Points 1 and 2 and Color Sample 2 provided below falls on the line connecting Points 3 and 4:

1 2

3.5 Weld Quality: A basic requirement of all welds is thorough fusion of weld and base metal and of successive layers of weld metal. Welds should not be handicapped by craters, undercutting, overlap, porosity, or cracks.

3.6 Workmanship: The completed buoy shall be free of any cracks, wrinkles, holes or gouges. The color and finish of the buoy are to be uniform and free of foreign matter. Extra material at the parting lines shall be removed. Any parting agent residue on the surface of the buoy shall be removed. The surface finish shall be smooth.

3.7 Marking: Buoys shall be permanently marked with three lines of alpha-numeric characters which shall be located on the top flat part of the hull, as shown in the drawing. Block digits at least 3/4 inch high and not higher than 1 inch shall be used for letters and numerals. The first line of this marking shall be the letters "USCG". The second line on buoys with NUN daymarks shall be the letters and number "FNR4". The second line on buoys with CAN daymarks shall be the letters and number "FCR4". The third line shall be the numeric digit(s) for month built and the last two digits of the year built, separated by a dash. After contract award, a two-letter code will be assigned to the Contractor by the Contracting Officer. This two-letter manufacturer's code shall form a part of the third line and shall be separated from the date built by a space. Permanent markings shall be molded or engraved into the hull.

3.8 First Article Tests: One complete CAN and one complete NUN buoy shall be the first articles.

## 4.0 QUALITY ASSURANCE PROVISIONS

4.1 The Contractor shall be responsible for the conduct of all tests required by the contract. He shall provide all space, personnel, and test equipment necessary for the conduct of the tests. The Contractor shall notify the Contracting Officer ten (10) days prior to the commencement of any of the tests required by contract. This testing will be witnessed by a Government Representative. Any buoys subjected to destructive testing shall not be included as deliverables under the contract.

4.2 First Article Tests: The Contractor shall perform the test set forth in Sections 4.2.1, 4.2.2, 4.2.3, 4.2.4, and 4.2.5. The Government Representative will observe the testing.

4.2.1 General: Testing will include the measurement of some or all dimensions to insure they are within the specified tolerance. First article tests will also include a check of exterior color, surface finish, external weld quality, and workmanship.

4.2.2 Strength of Hardware Test: A 3000 pound load shall be applied between the lifting tee and mooring eye. If permanent deformation of the steel hardware results due to manufacturing defect in material, weld, or fabrication, the buoy shall be considered to have failed the test.

4.2.3 Shell Thickness: The shell thickness of the buoy hull and daymark shall be measured by cutting the hull and daymark into equal quarters, and using a micrometer, measuring the thickness of the shell along the cutting lines. If the shell thickness falls outside the specified tolerances, the buoy shall be considered to have failed the test.

4.2.4 Foam Voids and Quality: The same hull that is cut open to check the shell thickness shall also be examined for foam voids and foam quality. Any foam void larger than 6 inches in diameter or with a volume of greater than 113 cubic inches shall cause the buoy to be considered to have failed the test. Foam samples taken from the buoy shall be subjected to the tests outlined in MIL-P-21929 to determine conformance. Failure of the sample to conform to MIL-P-21929 shall cause the buoy to be considered to have failed the test.

4.2.5 Crosslinking of Shell Material: Samples of the buoy shell material shall be subjected to the tests outlined in ASTM Specification D-2765-68, Method A or B, to determine the percent of extract. Alternate methods for determining this percentage may be used if found acceptable to the Government Representative. If the percent of extract is in excess of 13 percent, the buoy shall be considered to have failed the test.

4.2.6 First Article Test Reports: The Contractor shall prepare and submit to the Government test reports setting forth the results of the required tests.

4.3 Production Inspection

4.3.1 Production Sampling: Samples for inspection of these buoys shall be selected from each lot in accordance with Table 1.

TABLE 1

| Number of Buoys in Lot | Number of Samples | Acceptance Number |
|---|---|---|
| 2-8 | 3 | 0 |
| 9-15 | 5 | 0 |
| 16-25 | 8 | 1 |
| 26-50 | 13 | 1 |
| 51-90 | 20 | 2 |
| 91-150 | 32 | 3 |
| 151-280 | 50 | 5 |
| 281-500 | 80 | 7 |

4.3.2 Lot: For the purpose of inspection of these buoys, a lot shall consist of all items of the same class (CAN or NUN) offered for inspections at the same time. There shall be no more than four lots of CAN buoys and no more than four lots of NUN buoys.

4.3.3 Inspection: Samples selected in accordance with Section 4.3.1 will be inspected by the Government Representative to determine conformance to this specification. The inspection will include the measurement of some or all dimensions to insure they are within the specified tolerances. Inspection will also include a check of color, surface finish, external weld quality and workmanship. One buoy from each lot shall be subjected to the strength of hardware test outlined in Section 4.2.2. If this buoy fails the test, all samples selected in accordance with Section 4.3.1 shall be subjected to the test.

4.3.4 Rejections: If the cumulative number of defective samples is equal to or less than the acceptance number shown in Table 1, the lot will be accepted. If the number of the defective samples exceeds the acceptance number, a second set of samples shall be selected, in an amount doubling that taken originally, and the acceptance number shall also be doubled except where that acceptance number is zero, in which case it shall become one. If the number of defective samples exceeds the second acceptance number, the lot shall be rejected.

4.3.5 Shell Material Testing: Section 3.2.2 of this specification requires the cutting of a 1- to 2-inch diameter hole in the buoy hull, on the flat part of the deck as shown in the drawing. This hole shall be cut with a drill-mounted hole cutter and the plastic plug that is removed shall be saved. The Government Representative will require that samples of the plug selected in accordance with Table 1 be subjected to testing to determine the level of crosslinking and conformance to the requirements of Section 3.2.1 of this specification. Rejections of the lot shall be as outlined in Section 4.3.4 of this specification.

5.0 PREPARATION FOR DELIVERY

5.1 General: The buoys shall be shipped in three separate pieces; the hull assembly, the daymark, and the radar reflector assembly. The number of black hulls, CAN daymarks, and radar reflector assemblies shipped at any one time must be equal. The number of red hulls, NUN daymarks, and radar reflector assemblies shipped at any one time must be equal.

5.2 Packaging

5.2.1 Hull Assembly: The hull assembly does not require packaging or preservation prior to shipment.

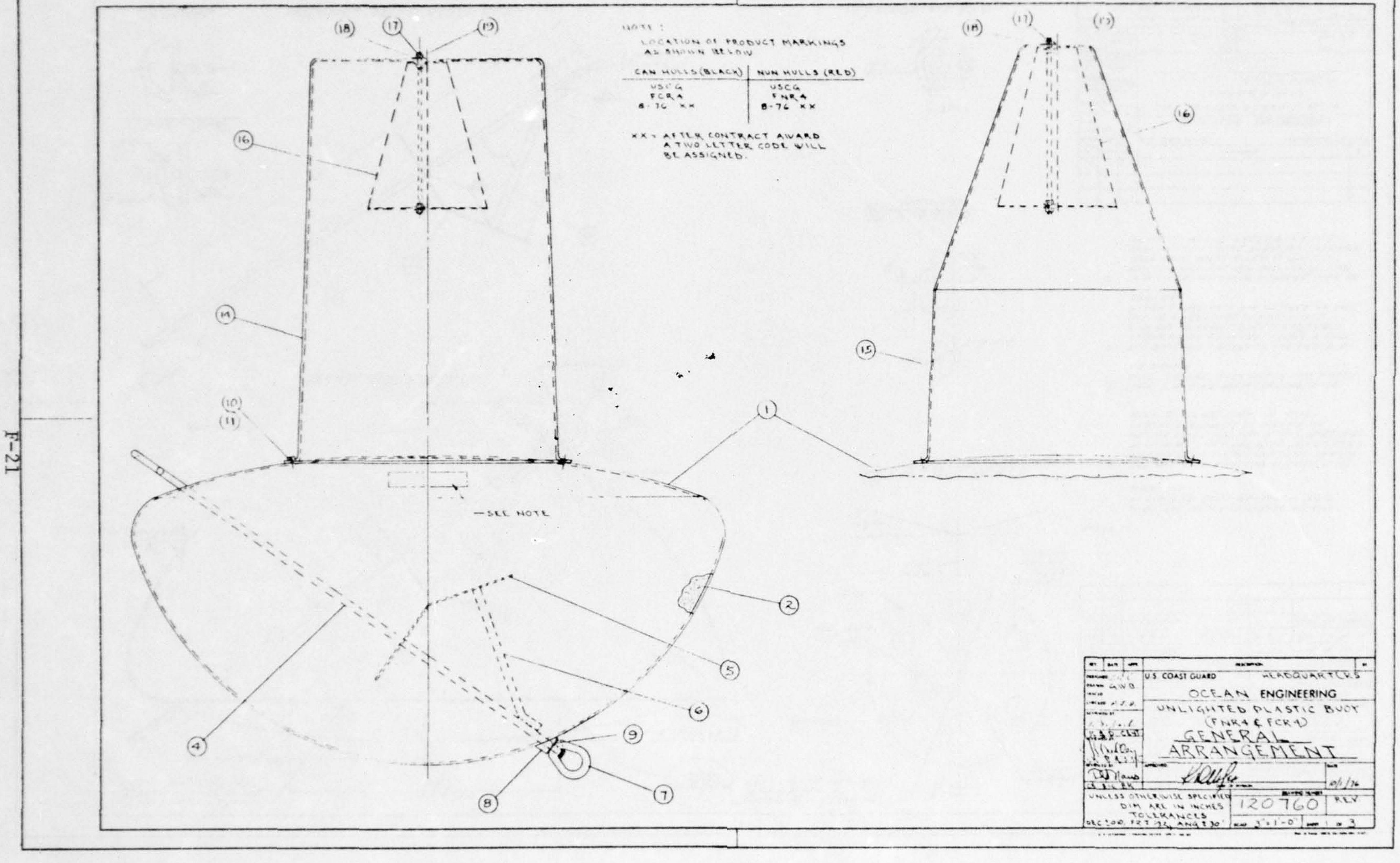
5.2.2 Daymarks: The daymarks do not require packaging or preservation prior to shipment. However, if the daymarks are stacked one on top of another, a spacer shall be placed between the daymarks such that sticking does not occur. If daymarks are stacked, the number of daymarks shall not exceed ten (10) in any one stack and at no time shall CAN and NUN daymarks be mixed in a stack.

5.2.3 Radar Reflector Assembly: These items shall be packaged for shipment in accordance with Military Specification MIL-P-116, Method III, for domestic shipment. No preservation is required. The number of radar reflector assemblies in any one package shall not exceed twenty (20).

5.3 Marking: The marking of the buoy hull is as outlined in Section 3.7. The daymark does not require any marking. The radar reflector assemblies package shall be marked with the quantity of assemblies in each package.

6.0 NOTES

6.1 Destructive Testing: The first article tests includes destructive testing of one complete CAN buoy and one complete NUN buoy. If a buoy fails the testing, a second destructive test on another will be required. Any buoy subjected to destructive testing shall not be included as a deliverable under the contact; however, salvagable parts (steel work), if undamaged, may be used in production.


NOTE:
LOCATION OF PRODUCT MARKINGS AS SHOWN BELOW
CAN HULLS (BLACK)
USCG
FCR4
8-76 XX
NUN HULLS (RED)
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FNR4
8-76 XX
XX = AFTER CONTRACT AWARD A TWO LETTER CODE WILL BE ASSIGNED.
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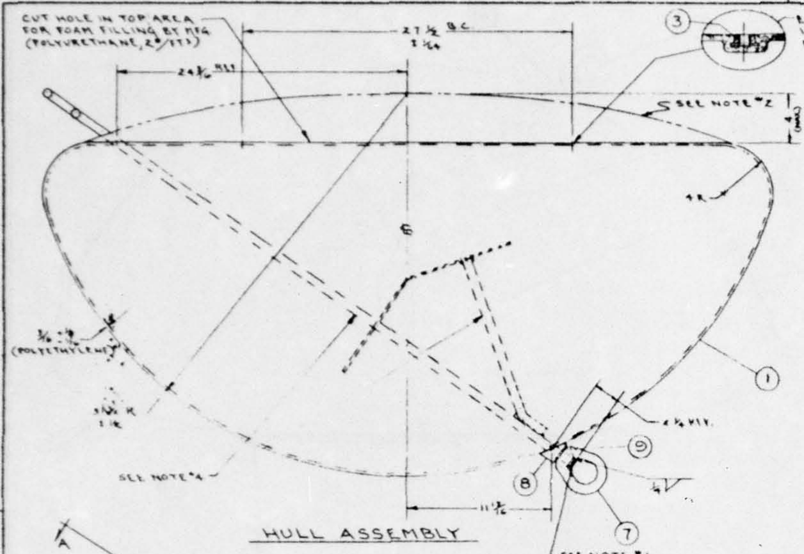
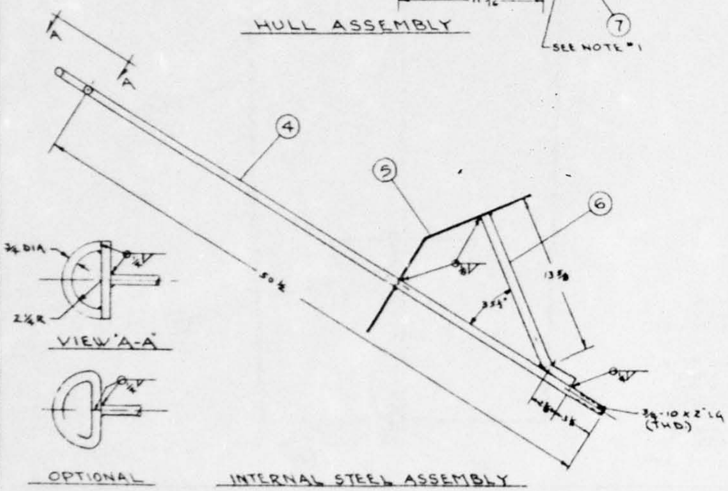
GENERAL ARRANGEMENT
UNLESS OTHERWISE SPECIFIED DIM. ARE IN INCHES
TOLERANCES
120760



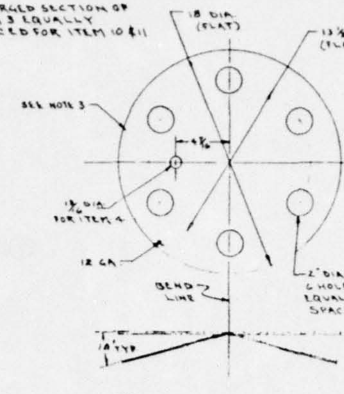

HULL ASSEMBLY



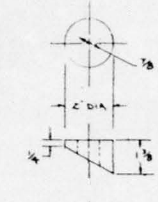

VIEW 'A-A'

OPTIONAL

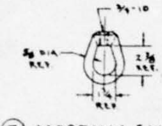
INTERNAL STEEL ASSEMBLY




(5) ANCHOR PLATE




(8) BUSHING (HALF SIZE)




(7) MOORING EYE

BILL OF MATERIALS

| ITEM NO | NO REQD | DESCRIPTION | MATL | REMARKS |
|---|---|---|---|---|
| 1 | 1 | BUOY HULL SHELL | POLYETH. | ROTATIONALLY MOLDED |
| 2 | 1 | FOAM | POLYURE. | 2#/FT³ |
| 3 | 12 | THREADED INSERT | STL | 3/8-16 THD |
| 4 | 1 | MOORING ROD | | 3/4 DIA. |
| 5 | 1 | ANCHOR PLATE | | 12 GA SEE NOTE BELOW |
| 6 | 1 | " " ROD | | 3/4 DIA. |
| 7 | 1 | MOORING EYE | | [illegible] |
| 8 | 1 | " " BUSHING | PVC | PLASTIC ROD |
| 9 | 1 | WASHER | STL | FOR 3/4 ROD |
| 10 | 12 | SLOTTED HEX. HD. SCREW | S STL | 3/8-16 x 3/4 LG |
| 11 | 12 | WASHER | " " | (FOR 3/8 SCREW) |
| | | | | |
| | | | | |

NOTES:

1. HEAT THE ROD END DURING MOLDING TO ACHIEVE BOND BETWEEN ROD AND HULL.
2. TOP MAY RISE A MAX OF 4" WHEN FOAM FILLING ITEM 1. CARE SHALL BE TAKEN TO INSURE THAT THE RISE THAT TAKES PLACE DOES NOT CAUSE ANY THREADED INSERTS (ITEM 3) TO DIFFER IN RISE BY MORE THAN 1/2 INCH.
3. ITEM 5 MAY BE MANUFACTURED AS A 18" SQUARE WITH HOLES AND ANGLE AS SHOWN.
4. THE BUOY HULL SHAPE IS BASICALLY A SEGMENT OF A SPHERE. ITEMS 4 AND 6 OF THE INTERNAL STEEL ASSEMBLY LIE IN A VERTICAL PLANE WHICH PASSES THROUGH THE CENTER OF THE SPHERE.
5. 1/8 DIA VENT HOLES OR SMALLER, MAY BE DRILLED INTO THE TOP SURFACE OF THE BUOY HULL SHELL (ITEM 1) FOR GAS DISCHARGE DURING FOAMING. NUMBER OF HOLES NOT TO EXCEED TWELVE.

U.S. COAST GUARD HEADQUARTERS
OCEAN ENGINEERING
UNLIGHTED PLASTIC BUOY (FNR4 & FCR4)
HULL ASSEMBLY
DETAILS

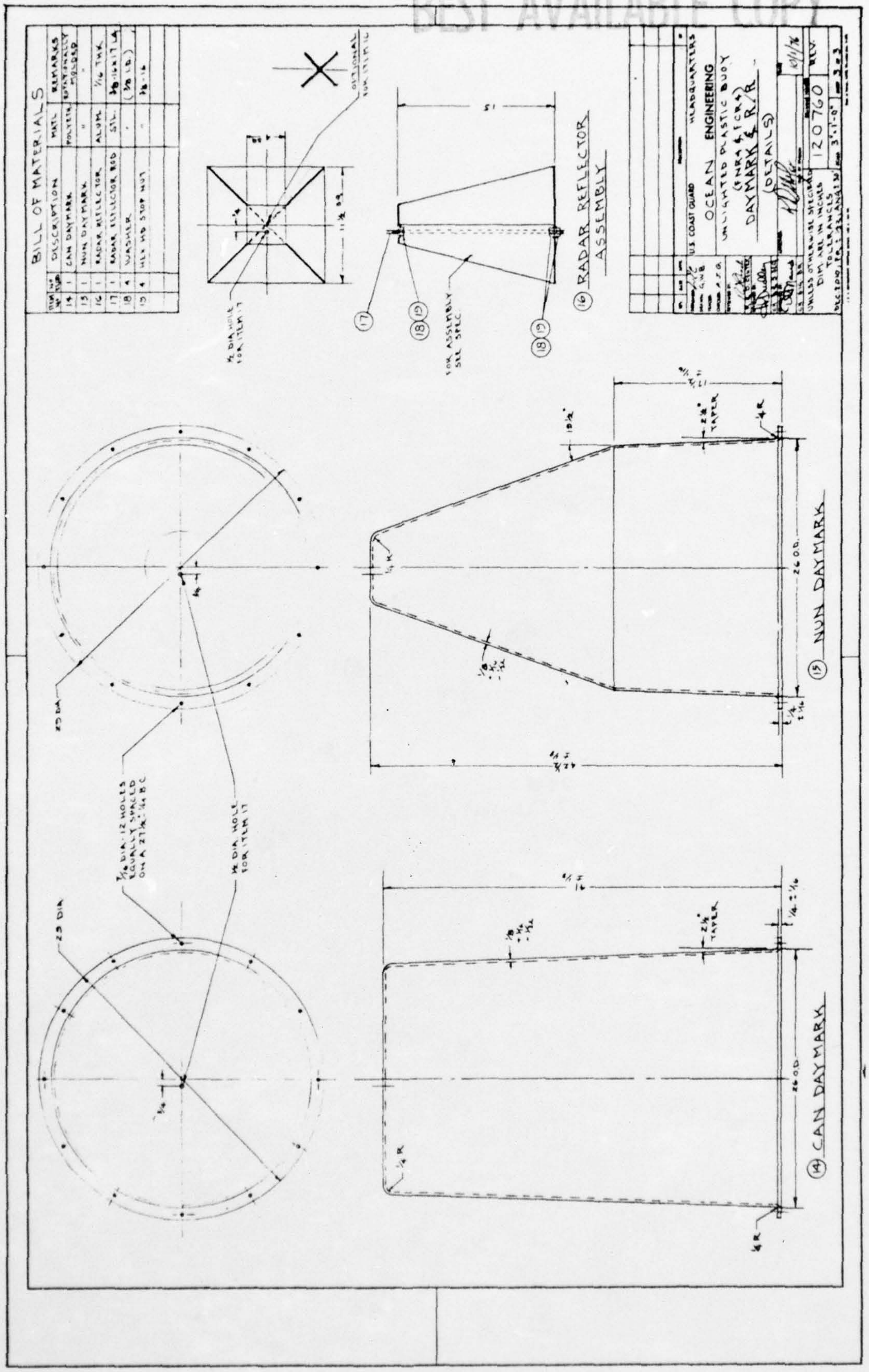
DESIGNED L.P.C. DRAWN G.W.B. CHECKED A.J.G.

DATE 10/1/76

UNLESS OTHERWISE SPECIFIED DIM. ARE IN INCHES
TOLERANCES DEC ±.010, FRT ±1/64, ANG ± 30'

DRAWING NUMBER 120760 REV.

SCALE AS NOTED 3" = 1'-0" SHEET 2 OF 3



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